Validation of Improved Comfort and Loading *with the* Center for Space Medicine Harness

Station Development Test Objective

PI Final Report

SDTO 17013-U

March 1, 2011

Submitted by:
G.Perusek, M.S., PI, NASA Glenn Research Center
T. Owings, D.Eng., Co-Investigator, Cleveland Clinic
J. Ryder,Ph.D., Co-Investigator, NASA Johnson Space Center
M. Savina and C. Sheehan, Technical Personnel, ZIN Technologies
Brian L. Davis, Ph.D., Co-Investigator, Austen BioInnovation Institute

Acknowledgements:

The authors wish to acknowledge the JSC Human Research Program for funding, the ISS Vehicle Office and Brian Vining for sponsorship, and ISS Medical Project team for their invaluable support during the planning and test operations phases of this project. In particular from JSC, Jeff Milstead, Mike Rapley, David Becker, Alonso Fuentes, Daniela Monterrubio, Scott Humbert, Tim Aramil, Rajib Dasgupta, and Tom Hunyady deserve special thanks.

The authors wish to acknowledge the invaluable contributions of Peter R. Cavanagh, Ph.D., D.Sc. and Sara Novotny for their insight, innovation, and advocacy during the initial stages of this project. Matthew Kuklis, Farhad Bahrehmand, and Ahmet Erdimer from the Cleveland Clinic are also acknowledged for their contributions.

With deepest appreciation to the team at Terrazign, Inc. in Portland, OR of Bill Dieter, Susanna Hohmann and Carly Mick, who are recognized for their highly collaborative spirit and innovative contributions in the development of the prototype design and flight harness softgoods.

Table of Contents

Acronyms

ADAS	Ambulatory Data Acquisition System
Adc	Analog to Digital conversion
ANOVA	Analysis of Variance
ASCR	Astronaut Strength Conditioning and Rehabilitation specialist
BME	Biomedical Engineer
BW	Bodyweight
CDR	Critical Design Review
CMS	Countermeasures Systems
CMS SPRT	Countermeasures Systems Special Problems and Resolution Team
CPHS	Committee for the Protection of Human Subjects
CSA	Canadian Space Agency
CSM	Center for Space Medicine
DBLS	Daily Bone Loading Stimulus study
DF	Degrees of Freedom
ESA	European Space Agency
eZLS	enhanced Zero-gravity Locomotion Simulator
GRC	Glenn Research Center
HRP	Human Research Program
HSRB	Human Systems Risk Board
IPV	ISS Procedures Viewer
IRB	Institutional Review Board
ISS	International Space Station
ISSMP	ISS Medical Project
JAXA	Japanese Space Agency
JSC	Johnson Space Center
L	Large
M	Medium
MAPTIS	Materials and Processes Technical Information System
MPH	miles per hour
NASA	National Aeronautics and Space Administration
NPR	NASA Procedural Requirement
P	Progress (Russian vehicle)
PI	Principal Investigator
PDR	Preliminary Design Review
S01	Subject number 1, etc. (also Sub001, etc.)
S	Small
SBS	Series Bungee System
SDTO	Station Development Test Objective
SE	Standard Error
SLD	Subject Load Device
T2	2nd ISS Treadmill (Colbert)
TVIS	Treadmill with Vibration Isolation and Stabilization
USOS	United States On-Orbit Segment
VCB	Vehicle Control Board
XL	Extra Large

Executive Summary

The weight-bearing exercise afforded by treadmill running on the ISS is thought to be crucial for effective gravitational loading of the musculoskeletal system and thus for bone health in space. The current ISS Treadmill Harness has caused discomfort in crewmembers, including chafing, bruising, and scarring at pressure points on the shoulders and hips, and may be a major contributor to sub-optimal loading on the treadmill.

From September 2009 through November 2010, a treadmill harness Station Development Test Objective (SDTO), sponsored by the Human Research Program's Exercise Countermeasures Project, collected on-orbit comfort and load data in a side-by-side comparison of the current Treadmill Harness and a new design, termed the "Glenn Harness" (formerly Center for Space Medicine, or CSM Harness) designed for improved comfort and loading. Operations began during Increment 20/21 and continued through Increment 25. A total of six (6) USOS crewmembers participated in the protocol.
This final report summarizes the SDTO objectives and results and describes the important features of the new Glenn Harness design including a comprehensive list of planned improvements for the operational Glenn Harness. Improved harnessing is expected to allow greater loading during exercise, potentially leading to greater health benefits from treadmill exercise, and should mitigate crew discomfort during exercise. As of this writing, the Crew Office has endorsed provision of Glenn Harness as a 'crew preference item' for USOS crewmembers, based on positive feedback from the crew.

Background and Justification

The Human Research Program sponsored development of a new harness for astronauts to wear on the International Space Station during treadmill exercise, which was evaluated by six (6) crewmembers between Increments 20/21 through 25 in a Station Development Test Objective (SDTO). The new harness design was originally called the "Center for Space Medicine" or CSM Harness, to honor the collaboration between NASA Glenn Research Center and the Cleveland Clinic, from which the harness prototype concept was developed. For purposes of Operations Nomenclature (Op Nom), the CSM Harness eventually became the "Glenn Harness" and is referred to as such herein. The Glenn Harness design is aimed at improving the comfort for crewmembers, who have reported nearly universally in post mission crew debriefs that the current Treadmill Harness is uncomfortable; causing pain, numbness, chafing, bruises, broken skin, bleeding and scarring at the shoulders and hips where the harness meets the body and bears load against the Subject Load Device (SLD). The SLD is required in microgravity to replace the body weight of the crewmember against the treadmill. The purpose of this Station Development Test Objective (SDTO) was to compare the comfort of the Glenn Harness to the existing Treadmill Harness through a series of on-orbit exercise sessions on the International Space Station, where the crewmember could report their feedback specifically about the comfort at specific anatomical locations, as well as collect data about the fit and function of the harness, and capture data relating to total load into the harness via the Subject Load Device, and the hip to shoulder load splits. From this information, the PI Team was able to glean information about how crewmembers were loading the harnesses, how they were adjusting them to distribute load, and how comfortable each harness was for them - in a side-by-side comparison.

Both the Glenn and Treadmill Harnesses were instrumented with load-sensing instrumentation developed specifically for this protocol to allow the PI Team insight into total loading and load distributions between the hips and shoulders during treadmill exercise.

In addition to the six crewmembers who participated, a second female subject opted out of the protocol due primarily to shoulder strap discomfort in the Glenn Harness (she would have been the 7th subject). The comfort data captured in the SDTO showed improvement in overall comfort with the Glenn Harness for four out of five male crewmembers, with the fifth expressing no preference. Neither female crewmember preferred the Glenn Harness, due primarily to the shoulder strap assembly discomfort near the armpits. The female shoulder strap assembly is undergoing design modifications and re-test based on results and recommendations vetted at the Human Systems Risk Board (1.5.11), Countermeasures Systems Special Problems and Resolution Team (1.12.11), and the Vehicle Control Board (1.24.11). Crew comments and debriefs were obtained for all seven crewmembers, and have been positive overall in terms of the Glenn Harness comfort, fit, and design. A crew debrief held in January 2011 provided valuable feedback from the two female crewmembers which will serve as the basis for shoulder strap design modifications to follow this year, which is planned to be tested in a ground-based treadmill simulator to prove it out. The Crew Office requested expedited development of an inventory for male crewmembers utilizing the Glenn Harness, and transition to operations as a Crew Preference Item, which is ultimately expected to result in an inventory of male and female harnesses in Small, Medium, Large and Extra Large. This Final Report includes a comprehensive list of planned improvements for the operational Glenn Harness including geometry, materials, and crew familiarity training.

Summary of Experiment

Seven (7) Glenn Harnesses and instrumentation were delivered and flown on HTV-1, Soyuz, and Shuttle to ISS between September, 2009 and March, 2010. Crewmembers ran an approved protocol using normal exercise time, at 60% and 90% bodyweight loading and compared Glenn Harness and Treadmill Harness ‘side-by-side’. Load data were captured on both Glenn and Treadmill Harness to provide hip:shoulder loading ratio and total load into each harness.

For the first month on-orbit, crewmembers used normal Treadmill Harness, then began the protocol, running a nominal four (4) data collection sessions with Glenn (or Treadmill) Harness, four (4) data collection sessions with Treadmill (or Glenn), with a nominal three (3) exercise sessions between data collection. For remainder of mission, if time remained, crewmembers could wear harness of choice. Crewmembers provided qualitative comfort / fit / function feedback via a Questionnaire after selected sessions for both harness types (Borg Scale, and Likert Scale).

Comfort data for each harness type were captured for all six crewmembers who participated in the protocol. The Likert scale (relating to form, fit, function) data were also obtained for all six crewmembers for each harness type. Crew debrief comments have been obtained for all seven crewmembers, providing good feedback. Overall, four (4) of five (5) male crewmembers preferred the Glenn Harness. One crewmember preferred the Glenn Harness exclusively, wearing it for the essentially the entire Increment, except for four (4) Treadmill Harness sessions (not per protocol). Both female crewmembers (one who participated as a subject, the other who opted out voluntarily) did not like the Glenn Harness shoulder straps, primarily because of discomfort near the armpits.

Load data were captured for Subjects 1, 2, and 6. Transducer signal issues arose during Subject 3, were troubleshot and fixed during the protocol for Subjects 4 and 5. The troubleshooting revealed cable strain relief issues and these were remedied by use of grey tape around the connections at the Ambulatory Data Acquisition Unit and the transducer buckle bodies themselves.

Design Features of the Glenn Harness

The Glenn Harness design (Figure 1) is based on a prototype (Figure 2, center) developed by collaborators [1], which was first developed from the key insight that treadmill harnesses, which tether the crewmember to the treadmill running surface in microgravity, serve to bear downward loading against the hips and shoulders much like a backpack harness does (Figure 2, left). Backpack harness components from Osprey Packs, Inc. (Cortez, CO) and Kelty (Boulder, CO) packs were adapted for use in initial prototypes. These prototypes consisted of a padded hip belt and shoulder strap assembly, modified with additional nylon webbing and D-rings at the hip belt to interface with the Subject Load Device (SLD) of the treadmill.

Figure 1: Glenn Harness front, side, and rear views

The prototypes were used in bed rest studies at the Cleveland Clinic (now the Daily Bone Loading Stimulus, or DBLS, study at University of Texas Medical Branch), evaluated against the Treadmill Harness in a ground-based comfort study at NASA Glenn [2], and are still used in ground-based simulators at both locations. The backpack-based prototype and Glenn flight harness derived from the prototype both feature closed cell foam padding at the hips and shoulders rather than the Aramid felt used in the Treadmill Harness. This padding is compression molded to provide a cupped and canted geometry in the hip belt, and the foam conforms to the wearer over time, which helps eliminate the pressure points which cause pain. One key difference in design approach between the current Treadmill Harness and new design is that the Glenn Harness, like its prototype predecessor, utilizes relatively stiff high-density foam across the outside surfaces of the hip belt and shoulder straps. This stiff 'outer shell' is a crucial feature to this design which allows loads from the SLD to be transferred across a larger surface area than the Treadmill Harness allows, and helps to minimize the pressure points observed with the Treadmill Harness, which can lead to pain, numbness, chafing, and scarring. The stiff outer shell of the hip belt is split about the iliac crests, allowing these bony protrusions to rest more comfortably within the lower density closed cell foam bearing against the body. The prototype and Glenn Harness have a separate, removable lumbar support (Figure 2, right), to further customize the fit based on the wearer's preference. To account for different body sizes, the prototype and Glenn Harness hip belt and shoulder strap assemblies are sized in Small, Medium, Large and Extra Large.

Figure 2. The collaborators introduced the notion that the form and function of a treadmill exercise harness is similar to a backpack harness (example shown at left). Prototype harness (center) and flight Glenn Harness (right).

The Glenn Harness diverges from the prototype in a few areas. Firstly, the materials were required to be certified for spaceflight (flammability and offgassing), therefore suitable replacements had to be found while retaining functional performance. The lower density closed cell foam in the hip belt was replaced with a foam of similar construction and durometer, but certified for spaceflight. The nylon webbing and fabric in the prototype were replaced with flight-approved Nomex webbing and cloth to meet flammability requirements. Also, based on crewmember feedback [3], a biocidal fabric was incorporated in the flight version to help minimize bacterial growth over the duration of an ISS mission, where the harness is worn and re-worn across dozens of exercise sessions without being able to be cleaned.

In addition to materials, the webbing configuration and back plane of the prototype were modified in the Glenn Harness, with the goal of improving performance and comfort. The rectilinear backplane of the prototype, designed to interface with a backpack, was streamlined and padded in the Glenn Harness to allow some load to be comfortably borne by the upper back. For the webbing at the hip belt, the bifurcated ‘Y-strap’ in the prototype, which transfers the SLD load to the hip belt in four places (two attachment points on each side) was revised to a three-legged strap (Figure 3), to further distribute load across the surface of the hip belt. The most rearward strap was run through a new set of adjustable cam-cleat buckles mounted at the back of the belt near the lumbar region, to permit the three-legged strap to be adjusted in length.

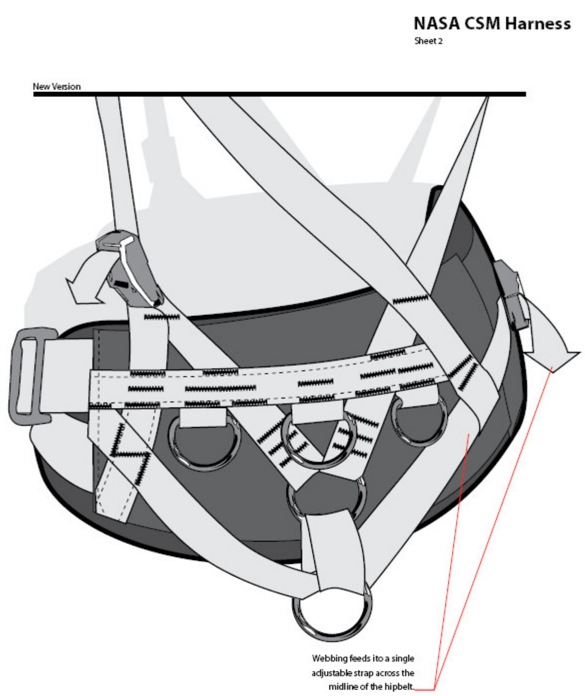
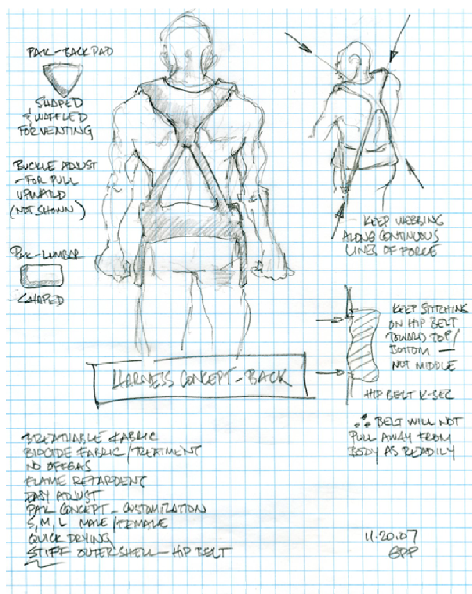


Figure 3: Flight Glenn Harness hip belt detail, showing new D-ring height adjust feature (see arrow on the right of sketch, or rear of hip belt) unique to the Glenn Harness. Webbing feeds into a single adjustable strap across the midline of the hip belt.

This new feature allows the wearer to cinch up the O-ring where a bungee French clip may attach, thus potentially replacing uncomfortable French Clips ganged together near the upper thigh, which are currently the only means provided to crewmembers to allow bungee load to be increased or reduced. Crewmembers alternately will gang the French Clips together near the treadmill belt, which appears to be a better alternative. These French Clips were highlighted in crew debriefs as a problem area with the Treadmill Harness comfort and one that, if properly addressed, might help to minimize chafing at the upper thigh during running – another common complaint of crewmembers using the Treadmill Harness with bungees. The backplane of the prototype, which is rectilinear in shape and designed to interface with a backpack, was reshaped to rest between the shoulder blades and on the upper back. The webbing in this area was revised to route in a criss-cross pattern, allowing loads to be transferred along axial lines of the webbing (Figure 4).

A few common-sense design features emerged in the development of the flight Glenn Harness. One was to not place buckles in direct contact with the body – to always position buckles over a padded area of the harness, or enclosed in padding (as with the sternum strap and front belt buckles) or, in the case of the buckle transducers, to encase them in a padded cover or 'buckle cozy'. Another design feature mentioned above, dictated that loads be carried along axial lines of webbing where possible, to exploit the high tensile strength of the



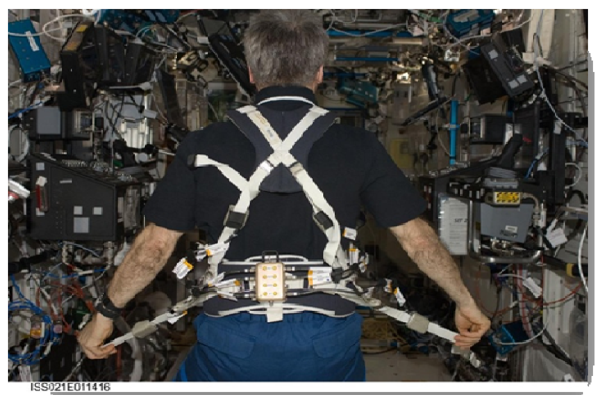


Figure 4: Glenn Harness concept back plane at left, final back plane implemented shown at right. Also visible at right are the junction box and buckle transducers.

webbing (as opposed to loads being borne by fabric or foam where off-axis loads may cause the belt to pucker or pull away from the body). Further, webbing was positioned such that lines of force were continuous, that is, directly opposed by webbing where possible. This dictated that the front strap of the shoulder padding be positioned to oppose the front leg of the three-legged "Y-strap", to avoid causing a forward pitching moment in the hip belt generated by an unopposed front leg of the Y-strap, and which may put undue pressure on the lumbar region. In the prototype, the shoulder strap assembly webbing running from the base of the front strap to the hip belt is comprised of a single strap (one on the left, one on the right) which attaches at the hip belt posterior to the greater trochanter. This front shoulder strap was bifurcated in the Glenn Harness design to attach anteriorly to the greater trochanter and oppose the Y-strap. This eliminated the forward pitching moment and allowed a static balance the forces in the hip belt to alleviate pressure in the lumbar area, which was observed anecdotally in ground tests to cause discomfort. In hindsight, this front strap may have served to defeat the S-shaped shoulder strap feature, which brings the load laterally to the chest and directs it away and under the armpits. For the female crewmembers in particular, the Glenn Harness shoulder straps were uncomfortable in this region, necessitating rethinking this area of the design. As of this writing, a new design concept has been vetted with both female crewmembers in a private debrief, and the PI Team is encouraged by their supportive feedback and go forward plan. A shoulder strap revision and retest are planned for later this year, after which the PI Team will plan to provide a recommendation on this design for implementation into an operational harness.

The measurement of total load and load distribution in each harness type required the development of innovative strain gauge based instrumentation designed to integrate in a non-invasive fashion with both harnesses. The Ambulatory Data Acquisition System (ADAS), an ISS verified flight system, was used to collect quantitative loading data during this SDTO. In addition to considerations for webbing and buckle configurations for improved load distribution and function throughout the harness, the load-sensing instrumentation, or 'buckle transducers' had to have places to attach, to provide total load and load distribution data. There had to be a minimum of length of clean webbing, that is, with no stitches or hems, whereby the buckle transducers could clip into this length and provide accurate and repeatable load data. For this reason, the front of the shoulder strap pad has a metal O-ring, through which a single piece of webbing passes, adjusted by a cam cleat buckle at the hip. This allowed all of the webbing to be accounted for in the load calculations, without actually having to instrument every leg of webbing. A total of six (6) load transducers were used on each harness – one at each hip, one at each of two front shoulder straps, and one at each of two rear shoulder straps (Figures 5a and 5b).

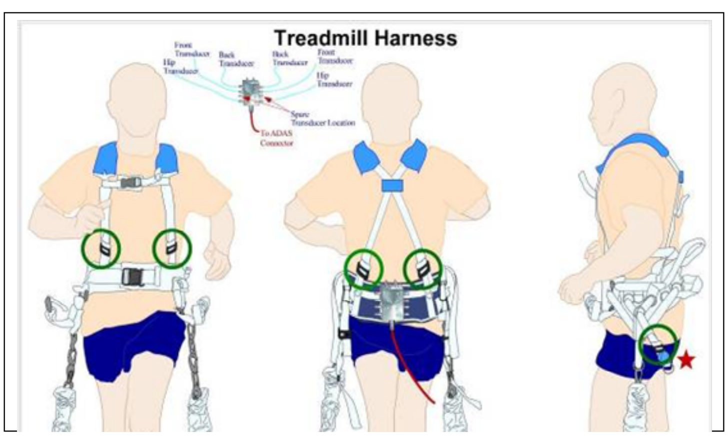


Figure 5a. Front, rear, and side views of Treadmill Harness showing locations (circled in green) of load-sensing instrumentation, which clipped non-invasively into each harness to provide total load (at hips) and hip:shoulder load ratio measurements on-orbit during the Harness SDTO.

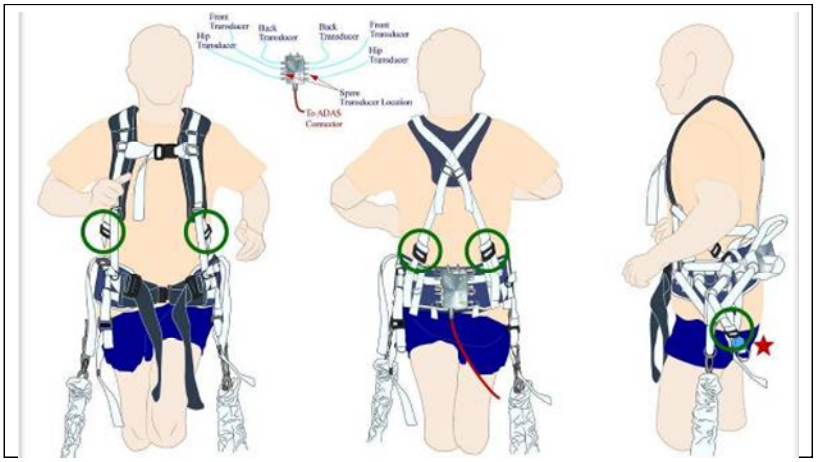


Figure 5b. Front, rear, and side views of Glenn Harness showing locations (circled in green) of load-sensing instrumentation, which clipped non-invasively into each harness to provide total load (at hips) and hip:shoulder load ratio measurements on-orbit during the Harness SDTO.

The Glenn Harness design (see Appendix H for final configuration) was reviewed in a process guided by NPR 7123.1A which included life cycle reviews Preliminary Design Review (PDR) and Critical Design Review (CDR) prior to flight hardware builds. The review boards were comprised of discipline experts (mechanical, electrical, structural, safety, quality) as well as Countermeasures Operations leads from NASA Johnson Space Center, and representatives from the ISS Medical Project. In addition, Human Factors evaluation with crewmembers provided valuable feedback and suggestions early in the project lifecycle [3]. The suggestion of biocidal fabric, for example, was made by a crewmember in the October, 2006 Human Factors evaluation, which was incorporated by the PI Team in the final flight design.

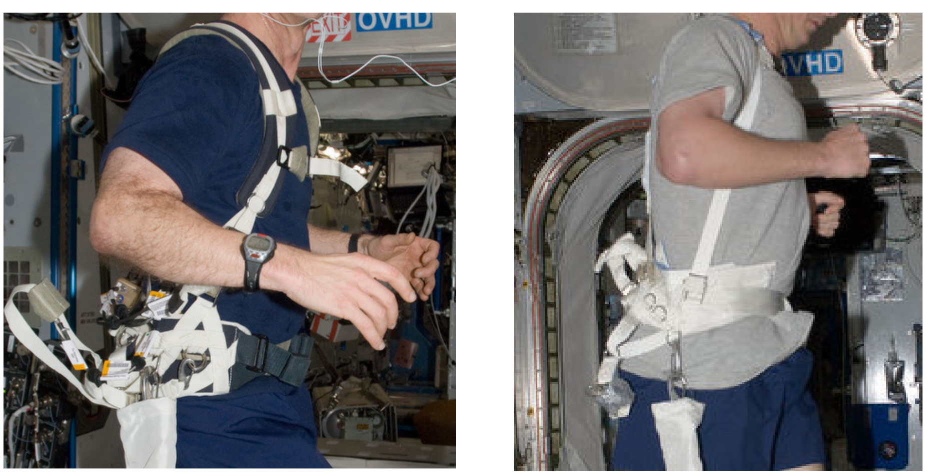


Figure 6: Glenn Harness is shown in use on ISS T2 treadmill at left, Treadmill Harness at right.

New Information Expected

The side-by-side comfort data as well as load and load distribution data collected in this SDTO had never before been collected on crewmembers exercising on the ISS treadmills. The Subject Load Device (bungee) loading is currently estimated using leg length and the force-deflection characteristics of the bungees. These data were collected via Buckle Transducer instrumentation for the first time, providing an understanding of the actual dynamic loading provided by the system (load input into the harness). What was found was that actual dynamic loading tended to be 15-20% lower on average than the Astronaut Strength Conditioning and Rehabilitation (ASCR) look-up table value. The load distribution data within the harness itself were also new data, providing insight into the harness loading and whether crewmembers are using what is understood to be optimal loading ratio configurations (i.e., 70% to the hips, 30% to the shoulders) [4,5]. What was found was that crewmembers participating in the SDTO tended to load their shoulders more than their hips with both harness types, which is reverse that of what is thought to be optimal. This points to a possible need to emphasize optimal loading ratios in the crew training, and having crewmembers run under load with their harness before the mission (e.g., on the T2 trainer at JSC). Crew debriefs have pointed to the desire in crewmembers to have more familiarity training with the harness before they fly, particularly with respect to making adjustments – for both proper fit, and for optimal load distribution.

Lastly, the new data were expected to provide insight into future designs. The crew feedback in particular was useful in this regard, especially with respect to female crewmembers, for which design improvements are planned to be implemented within the year.

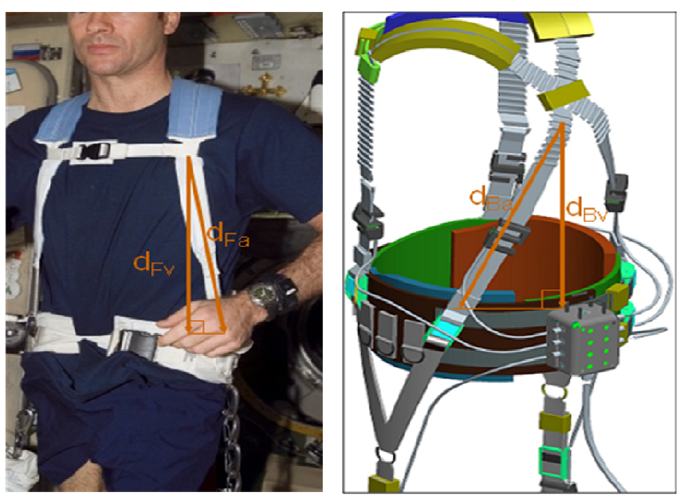
Methods

Six crewmembers (5 male, 5’11” +/- 2”, 199 lbs., +/-19 lbs. and 1 female 5’6”, 130 lbs.) participated in the protocol. Subjects were briefed at the crew Informed Consent Briefing by the PI prior to providing Informed Consent, which was approximately one year prior to their mission. The SDTO research protocol was approved by the JSC Committee for the Protection of Human Subjects, Human Research Multilateral Review Board, ESA, JAXA, and CSA for participation by USOS crewmembers. Crewmembers were trained in the use of the Glenn Harness and instrumentation system in a single crew training session prior to flight. In addition to signing Layman’s Summary and Informed Consent, the crewmembers filled out a ‘Crew Size Questionnaire” also approved by the Institutional Review Boards, which provided the PI Team with the belt and shoulder strap assembly size (S, M, L, or XL) for the Glenn Harness softgoods fabricator. Crewmembers were trained with the Glenn Harness crew trainer, which was a Men’s large size.

In addition to providing the PI Team anthropometric data (height, weight, belt size, torso length) prior to Glenn Harness flight builds, the subjects physical measurements of the each harness while donned by the crewmember were taken during crew training (see Figures 7 and 8).

Front Strap #1 [F1] | Front Strap #2 [F2] | Back Strap [B]

Figure 7: Physical measurements obtained from Glenn Harness for each subject during crew training.



Front Strap #1 [F1] | Front Strap #2 [F2]

Figure 8: Physical measurements obtained from Treadmill Harness for each subject during crew training.

During the on-orbit operations, crewmembers generated data files for each of the six Buckle Transducers – front shoulder strap (right and left sides), rear shoulder strap (right and left sides), and hip strap (right and left sides). Each data file sample from each of the Buckle Transducers was converted into a load in pounds. The shoulder harness strap geometry was then used to calculate the vertical load on the shoulders. Once the load on the shoulders was determined it was subtracted from the total SLD load (as measured by the Buckle Transducers in the two Hip locations) yielding the actual load on the hips.

The data files from each Buckle Transducer contain samples in ADC counts. By examining the raw file the 'zero' reading was observed, which was computed as an average of the first 1-2 seconds after the crewmember started recording data and before donning the harness when all Buckle Transducers were expected to be unloaded. Once the 'zero' reading was determined, it was saved as the 'offset' for that data channel. Each Buckle Transducer has a standard calibration constant that is the same for each unit with the same part number. Hence, each data file could then be converted from adc counts to pounds with the following formula:

$$F2L[pounds] = \frac{(F2L[adc] - Chan3offset[adc])}{BuckleCal[adc/pound]}$$

Where
F2L[adc] is an array of samples from the Front Strap #2 position

Each shoulder strap is typically not parallel to the direction of SLD load. Each strap makes an angle between its shoulder harness connection point and hip belt connection point. The strap angle can be calculated using the measurements shown in Figure 9 and similarly for the Treadmill Harness.

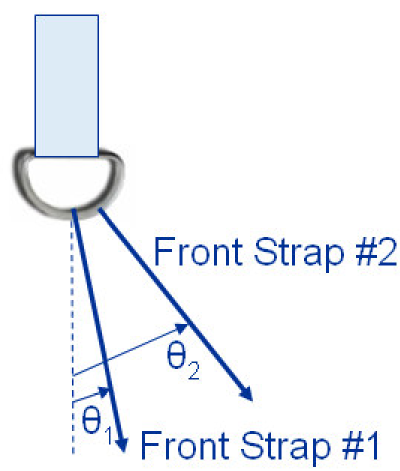


Figure 9: Strap tension projections to vertical – the D-ring shown accommodates a single nomex strap that provide 2 Front Strap attachment points down to the hip belt (not shown).

For each of the shoulder straps on both harnesses the projection of the measured force (strap tension) to the vertical direction is calculated in a similar manner as follows:

$$BVL[pounds] = \frac{BL[pounds] * dBv[inches]}{dBa[inches]}$$

Where:
BL[pounds] is an array of data points corresponding to the Back, Left strap tension
dBa[inches] is a measurement of the actual strap length
dBv[inches] is the measurement of the vertical projection of the strap length

For the Front shoulder straps on the Glenn Harness the two straps (#1 and #2) leading from each of the Front Left and Right D-rings are assumed to have equivalent tension. The two vectors must each be resolved in the same way:

$$FVL[pounds] = \frac{F1L[pounds] * dF1v[inches]}{dF1a[inches]} + \frac{F2L[pounds] * dF2v[inches]}{dF2a[inches]}$$

Where:
BL[pounds] is an array of data points corresponding to the Back, Left strap tension
dBa[inches] is a measurement of the actual strap length
dBv[inches] is the measurement of the vertical projection of the strap length

The load on the shoulders is then a sum of the four vertical loads at each of the strap connection points:

$$Fshldr = FVL + FVR + BVL + BVR$$

The load on the hips is then determined by subtraction:

$$Fhip = (HL + HR) - Fshldr$$

Where HL and HR are arrays of data points corresponding to the Left and Right SLD tensions.

Crewmembers also generated qualitative data in the form of answers to a questionnaire after the selected exercise sessions. The comfort questionnaire administered through the IPV was based on the 'Borg scale' for pain [6], where 0 represented 'no pain' and 10 represented 'worst imaginable pain'. The Borg scale and other questions related to form, fit and function are reprinted in Appendix B. The form, fit, and function questions were presented in a Likert scale, which is a 1-5 rating from "Strongly Disagree to Strongly Agree". In addition, some crewmembers provided narrative free-form responses in the Questionnaire in the provided field. These provided additional relevant information and feedback.

Experimental Protocol as Approved by JSC Institutional Review Board

In-flight procedures:

FD1~30 -- Harness evaluations will not occur during the first month aboard ISS. Normal use of TVIS with the Treadmill Harness may occur during this time.

FD30~90 --TVIS exercise schedule will occur according to nominal ISS ops. The crewmember will be randomly assigned to wear either the instrumented Treadmill Harness or the Glenn Harness for sixteen consecutive exercise sessions (~4-5 weeks). After this period the crewmember will wear the other harness for an additional sixteen consecutive exercise sessions.

The crewmember will perform their normal ASCR-advised TVIS routine 3 out of 4 sessions. On the 4th, 8th, 12th and 16th exercise session a harness evaluation exercise protocol will be used as detailed below:

15 min at load of 60% of body weight (BW) at the normal routine speed

3 min at 60% BW – 3 mph
3 min at 60% BW – 6 mph
3 min at 90% BW – 3 mph
3 min at 90% BW – 6 mph
Order of speed will be randomized, but the 90% BW load will always occur last to minimize reconfigurations of SBS bungee loading.

The following data will be collected during each harness evaluation exercise protocol:

Comfort data from a Modified Borg Scale (0-10 ratings for discomfort) at each body location: hips, waist, back, shoulders, neck, and overall comfort will be recorded and delivered by crewmembers on a weekly basis via ISS Procedures Viewer (IPV). The crewmembers will respond to a cue-card type questionnaire (see Appendix B).

Load distribution data (applied load from bungees, and load distribution between hips and shoulders for each harness) collected via ADAS flash drive. Data will be down-linked after each session.

Scheduling efforts should be made around ISS ops to avoid prolonged disruptions to either of the two 16-session harness evaluations (e.g. 12 days of docked ops would be considered a prolonged disruption).

Upon primary evaluation of each harness, the crewmember may use either harness for the remainder of the expedition during normal ASCR- advised TVIS exercise. Additional qualitative feedback may be volunteered.

Postflight comments / feedback regarding harness fit, comfort, adjustment and wear will be solicited from participating crewmembers and obtained as part of normal CMS crew debrief.

This study should utilize long-duration (a minimum of 16 weeks) crewmembers.

Statistical Analysis

Because of the small number of subjects, and the limited availability of crew time for hardware evaluations during ISS missions, it was not feasible to generate large enough data sets to allow inferential statistics to be performed. This is a common limitation of in-flight experiments on ISS with human participants.

Statistical analysis on the data set of n=6 was performed based on the following hypotheses:

1. The Glenn Harness will provide greater overall comfort than the Treadmill Harness as measured by subjective comfort ratings (Modified Borg 0-10 scale)

2. Crewmembers will be able to tolerate higher external loads from the subject load device and/or Series Bungee System (SBS) Bungees on the Treadmill with Vibration Isolation and Stabilization (TVIS) treadmill

3. Load distribution measurements collected with strain gauge instrumentation between shoulders and hips will correlate with subjective measures of comfort in these areas of the body

4. The Glenn Harness will provide more effective wear and adjustability than the Treadmill Harness as measured by subject crew comments / debriefs

The data from six crew members for each of the two harnesses were analyzed using the methods of repeat measures mixed models. The results of Objective 1 (the modified Borg scale) were examined to determine if there was a significant difference in the distribution of the Borg rating numbers between the two harnesses. The measurements of objective 2 are repeated, quantitative and continuous in nature. They were examined using ANOVA methods which allow for repeat measures. The correlation between strain gauge readings and subjective measures of comfort (Objective 3) were analyzed using the regression methods of repeat measures mixed models. The results of Objective 4 were analyzed using repeat measures categorical analysis to determine significant differences in Likert Scale responses ((strongly agree, agree, neither agree nor disagree, disagree, strongly disagree) regarding harness fit and adjustability.

The results of this analysis will, of necessity, be underpowered. However, this work should allow the identification of possibly significant trends in the data. The identification of such trends will help guide decisions concerning the two harnesses and focus the efforts of future studies.

Results and Discussion

Qualitative comfort data (Borg scale) and form, fit, function data (Likert scale) were obtained from all six (6) participating crewmembers. Quantitative load data (from load sensing intrumentation clipped into harness straps) were obtained for three (3) participating crewmembers. Although the SDTO protocol did not capture data such as ‘which harness did crewmembers prefer to wear when they had the choice’ the anectdotal feedback from the BMEs working console was that most crewmembers chose to wear the Glenn Harness between data sessions, and if time remained after completion of the test protocol, for the remainder of the mission. At least one crewmember wore the Glenn Harness exclusively throughout the mission, including the prescribed acclimation time (to about flight day 30) where the Treadmill Harness was supposed to be worn. This allowed a good test case of durability of the Glenn Harness over a six month mission, and provided the basis for recommendations for improving adhesive (Recommendations #4 and #5).

Known Deviations from Protocol

The exercise protocol was not followed precisely with respect to external load settings (Subject Load Device, or SLD, and bungees) and harness use. Non-compliance included crew scheduled activities and priorities necessitating eliminating some sessions between data takes to try and allow the full eight (8) instrumented sessions prior to crew return (nominal planned was three sessions between), undershooting the SLD load settings, and wearing the Glenn Harness during the acclimation period between Flight Day 1 and 30 when the Treadmill Harness was to be worn, for example. Continual communication between the PI team and the BME/ISSMP support team resulted in crew notes with respect to external load settings with some success. However, further concern exists with the T2 treadmill loading where bungees are the only loading method available, whereby in some crewmembers loading up to and above 90% bodyweight is not possible with only one bungee per side (two bungees total). As there is an ASCR/Flight Surgeon requirement that 2 bungees per side (four bungees total) may not be used by the crew during exercise sessions, full bodyweight loading, which is thought to be most beneficial for musculoskeletal health, is not achievable for all crewmembers. This is planned to be alleviated with the ESA Subject Load Device planned to be implemented on the T2 treadmill.

The first two crewmembers completed 16 of 16 planned exercise sessions on each harness, which included 4 data collection sessions for each harness type. The remaining four crewmembers did not provide complete datasets due to various factors outside of the PI Team’s control, including interference with other higher priority scheduled activities coupled with the low priority of running the SDTO protocol, IPV data file corruption (one file was lost in downlink or saving, one file had empty comfort values), having crewmembers use their scheduled time to troubleshoot transducers rather than provide data, or having to bypass the short strap in order to achieve the desired total load into the harness. In the instances where data collection sessions had to be sacrificed due to schedule conflicts, the PI Team opted to favor the Glenn Harness runs over Treadmill Harness runs in order to obtain as much data as possible on the Glenn Harness. Due to the above mentioned factors, the total of retrievable comfort data sessions is summarized in Table 1 as follows;

Number of Sessions where IPV Comfort Data Retrieved

Subject	Treadmill Harness	Glenn Harness
Sub 001:	4	4
Sub 002:	4	4
Sub 003:	3	4
Sub 004:	3	3
Sub 005:	2	4
Sub 006:	3	4

Table 1: Total data collection sessions where data were retrieved

The SDTO protocol was proposed originally for five (5) test subjects. However given the results and feedback from the first two subjects, during the first quarter of FY10, the two (2) contingency harnesses built to the specifications of two primes who had completed crew training were approved for manifesting on STS-132 for use on Expedition 24/25. The science rationale for increasing n from 5 to 7 was as follows; i) to reduce risk of further losing data/subjects ii) n=7 was expected to increase statistical strength in the data; iii) adding a 2nd female subject to the pool (up from 1) was expected provide additional insight/data related to geometry differences and harness fit between male and female crewmembers, potentially improving design for this population further, and; iv) provided additional opportunities to recover from protocol discrepancies (mentioned above). The 7th subject (would have been 2nd female subject) however, opted out of the protocol voluntarily, primarily due to shoulder strap discomfort near the armpits. This feedback was still indeed valuable, and is the basis for the Recommendation #1 found at the end of this report.

Load Data Results

Both the Glenn and Treadmill Harnesses were instrumented to measure loading during exercise. The quantitative load data, showing total static load, total average dynamic load, and hip:shoulder load ratios for each condition for each exercise session are presented in Appendix A.

Load data were captured for three of the six participating crewmembers (Sub 001, 002, and 006). To complete the protocol and obtain accurate and repeatable load data for the three crewmembers, a series of troubleshooting measures were planned and performed by participating crewmembers to address issues that arose during Sub 003 sessions. The problem was ultimately determined to be 1) poor strain relief at the ADAS to buckle cable and cable to buckle body, and 2) strain gage wire delamination and shearing at the buckle body surface. The strain relief problem was remedied by developing and implementing a "NASA grey tape" fix on-orbit. Two of the failed buckles were returned post-flight and inspected, and Non-Conformance Reporting done per standard Quality Assurance practices.

The PI team verified that there was Left/Right symmetry in the load data, providing an additional level of redundancy beyond the spare transducers provided in the Instrumentation Kits. Further, to mitigate the risk of losing load data, the project flight certified and delivered two (2) additional spare buckle transducers for manifest on 38P, to position these in time for the Expedition 24/25 crew.

Comfort Data Results

Qualitative comfort feedback data from each crewmember were obtained, administered through a questionnaire on the ISS Procedures Viewer (IPV). Plotted in the Appendix B are comfort data for each region against the actual load placed on the shoulders, as measured by the load sensing instrumentation. For each run, the %BW that the subject was exposed (e.g., 68%, 68%, 95%, 94% for S01 Run01 Treadmill Harness) was multiplied by the % that was exerted onto the shoulders (e.g., 68%, 70% 54%, 60%, respectively). From that, the maximum value was taken (there would ideally be 4 values per subject) and plotted against the comfort scores. The plots distinguish between the harness as well as the three subjects. The observation of note here is that the shoulders were bearing the brunt of the %BW loading in many cases. Crewmembers were given a target recommended 70:30 hip:shoulder ratio in the crew procedure, however they did not consistently set shoulder ratios at the optimal (putting more load on the hips). The load ratios are adjusted manually by the crewmember by cinching down on the shoulder straps to increase shoulder load, or letting out tension to relieve shoulder load; the fact that they chose to bear more load typically on the shoulders is interesting and points to considering further crew training or further debrief questions specifically on this topic.

The crew debrief comments and comments in the Comfort Questionnaire narrative tended to follow the comfort results (trending a preference of Glenn Harness over Treadmill Harness in 4 of 5 male crewmembers). In at least one case the crew narrative feedback provides a disclaimer (Sub 01, Back data – who found the shoulder portion of the Glenn Harness *more comfortable* than that of the Treadmill Harness, however rated back discomfort high because crewmember changed the loading 40:60 hips:shoulders, which caused excessive strain in the back, and drove the discomfort value higher.) This observation supports the recommendation for crew training to highlight the hip:shoulder optimal ratio of 70:30, to alleviate potential back strain and improve overall comfort. In general, crew comments should be viewed together with the data, as valuable insights can be gleaned from the comments in interpreting the data.

One would expect to see a positive correlation (increasing discomfort with increasing load at the shoulders) with the upper body regions – neck, shoulders, back, and null or negative correlation with the waist (i.e., as shoulder load increases, waist discomfort decreases). This appears to be somewhat consistent with the data, but the only statistically significant correlation occurred between the actual loads and the comfort score at the back ($P=0.02$). This correlation was confounded by S01 and the adjustment to place more load at the shoulders (see above disclaimer).

The PI team observed higher hip discomfort in the prototype harness in the precursor ground comfort study [2], while overall lower discomfort in the prototype harness. The team hypothesized that the more aggressive padding in the prototype harness hip area helped transfer load to the pelvic shelf and hips (thus alleviating load on the shoulders) rather than having the shoulders bear the brunt of the load as with the Treadmill Harness. With crewmembers *self-selecting* load distribution between hips and shoulders in the SDTO, it is difficult to generalize, however, crewmembers were fairly good at estimating hip:shoulder load ratio once it was set (see Appendix D).

There were no significant differences between the Glenn Harness and the Treadmill harness in actual or percent loads ($P>0.05$). Per exercise protocol, crew members were instructed to perform their TVIS routine at 60% BW and 90% BW for both the Glenn and the Treadmill Harness. These results show that the crew members were able to tolerate similar external loads regardless of harness condition.

The comfort data presented by harness type are presented in Appendix C. The basis for the data plots was a Borg scale for pain, a 0-10 scale, where 0 represents ‘no pain’ and 10 represents ‘worst imaginable pain’. The Glenn Harness was found to be significantly more comfortable than the Treadmill Harness at the shoulders (least-square means: Glenn Harness=2.52 and Treadmill Harness=3.42), waist (Glenn Harness=0.60 and Treadmill Harness=1.13), and overall (Glenn Harness=2.43 and Treadmill Harness=2.98), but less comfortable at the back (Glenn Harness=1.97 and Treadmill Harness=1.23; all $P<0.01$). No significant comfort differences were seen at the neck or hips ($P>0.05$).

Self-Reported Load Distribution vs. Actual Load Distribution Results

The chart in Appendix D quantified how good the crewmembers were at *estimating* their hip:shoulder loading ratio. For each data collection period, the actual loads differed slightly between the 4 trials (the two running speed conditions and the two %BW conditions). Presented in Appendix D are the averages of the four test conditions (walking and running at each of 60 and 90% total load) together to get one actual shoulder load per run (assumes the crewmember did not adjust the shoulder straps during the run).

This chart speaks to the ability of crewmembers to estimate their load distribution in the harness, such that a) if problems do arise with discomfort they can perhaps be identified as relating to load distribution and b) if an optimal load distribution is communicated, it seems likely that (for at least this reduced data set) crewmembers will be able to set distributions as instructed, in the absence of direct load-measuring technology.

There is no statistical difference between the crewmembers ability to estimate load distribution between harness type ($P>0.05$). The regression line for the Treadmill Harness does have a higher slope – possibly indicating a trend towards improved comfort in the shoulder straps of the Glenn Harness (for male crewmembers, as has been discussed).

Responses to Likert Scale Questions on Harness Form, Fit and Function

Appendix E presents results from the Likert Scale questions administered to the crewembers after their data collection runs through the ISS Procedures Viewer. These questions comprised the second part of the questionaire. Some questions were positive in nature, and some negative, so each result in the graph should be viewed relative to the specific question. Questions Q2, Q3, Q4, Q6, and Q8 are positive in nature (i.e., a higher value indicates agreement with a positive characteristic of the harness), whereas questions Q1, Q5, and Q9 are negative in nature (i.e., a higher value indicates agreement with some negative characteristic).

For clarity, each question is reprinted with the appropriate graph in the Appendix E. The numerical values in the bar graphs represent the number of crewmembers who responded in each category, averaged over their number (typically four) data collection runs for each harness. In some instances, the numerical values are fractional – this is because the crewmember may not have answered the same way for each run (they may have 'strongly agreed' after one exercise session, and only 'agreed' after another exercise session) – and the average value was presented in the bar graph. Crew members were asked to rate the statements 1 to 5 (strongly disagree to strongly agree). Statistically significant differences appeared between harness types in mean Likert scores for Questions 1-8. The questions with average response (±SE) and interpretations are reprinted below:

Q1: The hip belt folds or buckles when in use.
On average, crew members disagreed with this statement for both harness types (Glenn Harness = 1.11 (0.26) and Treadmill Harness = 1.53 (0.26)) indicating that neither harness buckled or folded when in use. Crew members disagreed more strongly when refering to the Glenn Harness ($P<0.01$).

Q2: The hip belt fits snugly about your waist.
Crew members, on average, agreed with this statement for the Glenn harness (3.64 (0.25)), but neither agreed nor disagreed with the statement for the Treadmill Harness (3.20 (0.25)). This implies that the Glenn Harness fit crew members more snugly about the waist than the Treadmill Harness ($P<0.01$).

Q3: The harness is effective in distributing load between the waist or hips and the shoulders.
Similar to the results of Q2, crew members, on average, agreed with this statement for the Glenn Harness (3.81 (0.19)), but neither agreed nor disagreed with the statement for the Treadmill Harness (3.07 (0.19)). Therefore, crew members felt that the Glenn Harness

was more effective than the Treadmill Harness in distributing load between the waist/hips and the shoulders ($P<0.01$).

Q4: The shoulder straps effectively spread load over the entire shoulder area
On average, crew members agreed with this statement for the Glenn Harness (3.56 (0.13)) but disagreed with this statement for the Treadmill Harness (2.15 (0.13)). Crew members felt that the shoulder straps of the Glenn Harness more effectively spread load over the entire shoulder area than did the Treadmill Harness ($P<0.01$).

Q5: The harness constricts the chest and impedes breathing
Crew members, on average, disagreed with this statement for both harness types (Glenn Harness = 1.96 (0.23) and Treadmill Harness = 1.58 (0.23)) indicating that neither harness constricts the chest and impedes breathing. Crew members disagreed more strongly when refering to the Treadmill Harness ($P<0.05$).

Q6: The fit of the harness is adequate
On average, crew members agreed with this statement for the Glenn Harness (3.72 (0.23)), but neither agreed nor disagreed with the statement for the Treadmill Harness (2.65 (0.23)). This implies that the Glenn Harness fit crew members more adequately than the Treadmill harness ($P<0.01$).

Q7: Each crew member needs an individual harness
For both harness types, all crew members agreed that individual harnesses are needed for each member (Glenn Harness = 4.72 (0.25) and Treadmill Harness = 4.44 (0.25)). Crew members agreed more strongly with this statement when refering to the Glenn Harness ($P<0.05$).

Q8: The harness provides sufficient adjustability
Crew members, on average, tended to agree with this statement for the Glenn Harness (3.58 (0.25), but neither agreed nor disagreed for the Treadmill harness (3.17 (0.25)). Crew members felt that the Glenn Harness provided more sufficient adjustability than the Treadmill harness ($P<0.01$).

Q9: Harness requires adjustment while exercising
Crew members, on average, neither agreed nor disagreed with this statement for both harness types (Glenn Harness = 2.41 (0. 36) and Treadmill Harness = 2.59 (0.37)). There was no statistical difference between responses for either harness type ($P>0.05$) indicating that crew members did not feel strongly about either harness requiring adjustability while exercising.

Concluding Remarks

The Harness SDTO provided the first ever side-by-side comparison for comfort and loading of the current Treadmill Harness with a new "Glenn Harness" design on orbit with six (6) participating USOS crewmembers during ISS Increments 20/21 thru 25.

This final report summarized the SDTO objectives and results, and described the important features of the new Glenn Harness design including a comprehensive list of recommended improvements for the operational Glenn Harness. As of this writing, the Crew Office has endorsed provision of Glenn Harness as a 'crew preference item' for USOS crewmembers, based on positive feedback from the crew.

The recommendations, listed below, are separated into two categories; 1) Female / Harness Modifications and Ground Test Verification, and 2) Male inventory for crew preference item. Based on the management direction in the Human Systems Risk Board (HSRB) and Vehicle Control Board (VCB) outbriefs, it is anticipated that the Human Research Program is to consider funding the recommendations in section 1), and the ISS Program is to consider funding recommendations in section 2).

Summary of Recommendations and Forward Actions

1) Female / Harness Modifications and Ground Test Verification;

Recommendation #1
Address female crewmembers concerns related to female shoulder strap assembly, plan redesign and ground test. Plan to model after five-point NASCAR belt (e.g., 'yoke style'), without crotch strap. Fabricate one assembly, to interface with existing women's medium hip belt. Test in an abbreviated ground study in the enhanced Zero-g Locomotion Simulator (eZLS). Confirm design changes also with female crewmembers, who offered to try in the T2 trainer at JSC under load.

> **Justification**
> Both female crewmembers found the SDTO Glenn Harness design uncomfortable near the armpits/outside of chest. Two revised mockups, post SDTO, were shown to the female crewmembers in private debrief (January 2011, after SDTO completion) and both preferred the yoke-style mockup.

Recommendation #2
Propose simplifying the hip belt stitch / Nomex webbing.

> **Justification**
> The hip belt webbing and stitching was reproduced fairly reliably from the Cleveland Clinic prototype, which was the version evaluated in ground testing

and bed rest. Observation was that some of this was driven by sewing machine limitations. However, more efficient layout could be implemented by the professional softgoods manufacturer, potentially saving labor hours (and cost) in future builds.

Recommendation #3
Research materials/suppliers for alternate biocidal fabric, anticipated to pass flammability. If not located in MAPTIS materials database, conduct flammability test.

Justification
The big advantage here is that the containment bag could be eliminated, and if biocidal fabric is kept, harnesses could possibly be shared in a contingency situation.

Otherwise, second choice is to replace Gehring biocidal fabric with new non-biocidal fabric, to eliminate dependence on containment bag. The containment bag provides fire safety, and although it has perforations for breathability (so harness may dry out between sessions), the containment bag was not regularly used on-orbit, presenting a safety issue.

Recommendation #4
Investigate replacing the current web adhesive holding Gehring biocidal fabric to foam with Bemis or suitable web polyurethane adhesive to eliminate the shearing/delamination in the shoulder strap assembly.

Justification
Delamination of the Gehring fabric with Zote foam (which is one fluorine molecule away from Teflon) occurred on the Sub004 Glenn Harness which was worn for basically the duration of the Increment. This is primarily a cosmetic issue, however the concern is that if the delamination continued the fabric could bag and possibly catch on something. The ‘web polyurethane’ adhesive conforms to irregular surfaces like the insides of shoulder strap assembly neatly, without causing wrinkles and possible pressure points of a solid sheet adhesive.

Recommendation #5
Investigate replacing fabric, adhesive, and/or retooling for hip belt to eliminate delamination at hip belt fabric to foam interface.

Justification
Delamination of the Gehring fabric with Zote foam (which is one fluorine molecule away from Teflon) occurred on the Sub004 Glenn Harness which was worn for basically the duration of the Increment. This is primarily a cosmetic issue, however the concern is that if the delamination continued the fabric could bag and possibly catch on something. The ‘web polyurethane’ adhesive conforms to irregular surfaces like the insides of hip belt neatly, without causing wrinkles and possible pressure points of a solid sheet adhesive.

The work to identify alternate material for biocide, hip belt stitching could potentially save costs over long run (no containment bag, less labor on stitching) – but could affect comfort, and should be ground tested to verify comfort was not adversely affected, so these are book kept under the Female/Harness modifications estimate – as above.

2) Male Inventory for Crew Preference Item

Recommendation #6

Investigate replacement stiff outer foam material/supplier, procure, and repeat offgas testing.

Justification
SDTO hip belt outer foam shell was cannibalized from Osprey backpack hip belts. Osprey no longer supplies these and NASA needs to source / flight certify the replacement.

Recommendation #7
Eliminate raised weld seam and re-chrome plate the metal D-rings / metal O-rings in future harness builds.

Justification
Upon return of de-orbited used harnesses, the Nomex strap at the metal rings for Sub004 was beginning to fray, and the raised weld was identified as the culprit. This should be ground to smooth out the D-ring so the Nomex strap does not wear against it and fray.

Recommendation #8
Round out the hip belt compression molding tool inventory, for all Male sizes. Includes laser scanning of Osprey belt, creating digital file, machining the high density polyurethane foam tooling.

Justification
The male sizes Small (S) and Extra Large (XL) were not needed thus not built for the crewmembers participating in the SDTO protocol to save costs. The high density polyurethane will last ~20 molds, after which time it will need replacing. Alternate is to make tooling out of metal (i.e., aluminum) for durability, with initial up front costs higher. The assumption is that the items above will allow a near-term inventory capability of ~ 20 units per year for one year. Beyond that, estimate heavier-duty hip belt tooling costs, for the long run, vs. re-machining the foam tooling and throwing away after they get worn.

Recommendation #9
Provide familiarity training with the harness before crewmembers fly, particularly with respect to making adjustments – both for proper fit, and for optimal load distribution.

Justification
The crew debrief comments, narrative feedback on the IPV questionnaire and SDTO load distribution data all support this recommendation. The load distribution data within the harness itself provided insight into the harness loading and whether crewmembers were using what is understood to be optimal loading ratio configurations (i.e., 70% to the hips, 30% to the shoulders). What was found was that crewmembers participating in the SDTO tended to load their shoulders more than their hips with both harness types, which is not optimal. This points to a possible need to emphasize optimal loading ratios in the crew training, and having crewmembers run under load with their harness before the mission (e.g., on the T2 trainer at JSC), which may improve their comfort level even further.

Appendix A: Reduced Load Data

Subject 001 (S01)				TVIS				GLENN		
				Actual Avg. % of BW	[LBS]	[%]		Actual Avg. % of BW	[LBS]	[%]
60% BW	3MPH	Total (SLD)	Run 01-Static Loads Measured; 187-lb (105%); 130-lb (73%)	68%	120	100%	Run 05 Static Loads Measured; 186-lb (105%); 130-lb (73%)	64%	113	100%
		Shoulders			81	68%			76	67%
		Hips			39	33%			37	33%
	6MPH	Total (SLD)		68%	120	100%		64%	114	100%
		Shoulders			84	70%			82	72%
		Hips			36	30%			33	29%
90% BW	3MPH	Total (SLD)		95%	168	100%		97%	172	100%
		Shoulders			90	54%			107	62%
		Hips			78	46%			65	38%
	6MPH	Total (SLD)		94%	167	100%		95%	169	100%
		Shoulders			100	60%			114	67%
		Hips			67	40%			55	33%
60% BW	3MPH	Total (SLD)	Run 02 Static Loads Measured; 184-lb (104%); 132-lb (75%)	67%	118	100%	Run 06 Static Loads Measured; 186-lb (105%); 132-lb (75%)	66%	117	100%
		Shoulders			72	61%			72	62%
		Hips			46	39%			45	38%
	6MPH	Total (SLD)		66%	117	100%		66%	116	100%
		Shoulders			76	65%			79	68%
		Hips			41	35%			38	33%
90% BW	3MPH	Total (SLD)		97%	172	100%		95%	168	100%
		Shoulders			86	50%			96	57%
		Hips			86	50%			72	43%
	6MPH	Total (SLD)		95%	168	100%		95%	169	100%
		Shoulders			94	56%			109	64%
		Hips			74	44%			60	36%
60% BW	3MPH	Total (SLD)	Run 03 Static Loads Measured; 182-lb (103%); 128-lb (72%)	67%	119	100%	Run 07 Static Loads Measured; 188-lb (106%); 131-lb (74%)	67%	119	100%
		Shoulders			74	62%			83	70%
		Hips			45	38%			36	30%
	6MPH	Total (SLD)		67%	118	100%		66%	116	100%
		Shoulders			79	67%			89	77%
		Hips			38	32%			27	23%
90% BW	3MPH	Total (SLD)		95%	169	100%		95%	169	100%
		Shoulders			85	50%			105	62%
		Hips			84	50%			63	37%
	6MPH	Total (SLD)		94%	166	100%		95%	168	100%
		Shoulders			97	58%			123	73%
		Hips			69	42%			44	26%
60% BW	3MPH	Total (SLD)	Run 04 Static Loads Measured; 184-lb (104%); 127-lb (72%)	66%	116	100%	Run 08 Static Loads Measured; 145-lb (82%); 137-lb (77%)	72%	127	100%
		Shoulders			77	66%			95	75%
		Hips			39	34%			32	25%
	6MPH	Total (SLD)		66%	115	100%		72%	128	100%
		Shoulders			79	69%			100	78%
		Hips			36	31%			28	22%
90% BW	3MPH	Total (SLD)		94%	167	100%		79%	139	100%
		Shoulders			84	50%			100	72%
		Hips			82	49%			39	28%
	6MPH	Total (SLD)		94%	167	100%		79%	140	100%
		Shoulders			91	54%			109	78%
		Hips			77	46%			31	22%

Subject 002 (S02)				TVIS				GLENN		
				Actual Avg. % of BW	[LBS]	[%]		Actual Avg. % of BW	[LBS]	[%]
60% BW	3MPH	Total (SLD)	Run 01A-Static Loads Measured; 108-lb (83%); 95-lb (73%)	67%	87	100%	Run 05 Static Loads Measured; 114-lb (88%); 100-lb (77%)	71%	92	100%
		Shoulders			23	26%			40	43%
		Hips			64	74%			52	57%
	6MPH	Total (SLD)		65%	84	100%		65%	84	100%
		Shoulders			25	30%			42	50%
		Hips			59	70%			42	50%
90% BW	3MPH	Total (SLD)		76%	99	100%		82%	107	100%
		Shoulders			25	25%			44	41%
		Hips			74	75%			64	60%
	6MPH	Total (SLD)		72%	94	100%		75%	98	100%
		Shoulders			28	30%			45	46%
		Hips			67	71%			53	54%
60% BW	3MPH	Total (SLD)	Run 02 Static Loads Measured; 112-lb (86%); 104-lb (80%)	75%	97	100%	Run 06 Static Loads Measured; 110-lb (85%); 94-lb (72%)	69%	90	100%
		Shoulders			65	67%			38	42%
		Hips			32	33%			52	58%
	6MPH	Total (SLD)		70%	91	100%		65%	84	100%
		Shoulders			64	70%			38	45%
		Hips			27	30%			46	55%
90% BW	3MPH	Total (SLD)		82%	106	100%		81%	105	100%
		Shoulders			68	64%			44	42%
		Hips			38	36%			61	58%
	6MPH	Total (SLD)		75%	97	100%		72%	94	100%
		Shoulders			65	67%			41	44%
		Hips			32	33%			53	56%
60% BW	3MPH	Total (SLD)	Run 03 Static Loads Measured; 113-lb (87%); 95-lb (73%)	69%	90	100%	Run 07 Static Loads Measured; 110-lb (85%); 95-lb (73%)	67%	88	100%
		Shoulders			47	52%			35	40%
		Hips			43	48%			53	60%
	6MPH	Total (SLD)		65%	85	100%		63%	82	100%
		Shoulders			48	56%			39	48%
		Hips			37	44%			43	52%
90% BW	3MPH	Total (SLD)		81%	105	100%		80%	105	100%
		Shoulders			50	48%			39	37%
		Hips			55	52%			66	63%
	6MPH	Total (SLD)		77%	100	100%		75%	98	100%
		Shoulders			52	52%			49	50%
		Hips			48	48%			49	50%
60% BW	3MPH	Total (SLD)	Run 04 Static Loads Measured; 112-lb (86%); 95-lb (73%)	69%	90	100%	Run 08 Static Loads Measured; 110-lb (85%); 95-lb (73%)	67%	88	100%
		Shoulders			51	57%			30	34%
		Hips			40	44%			58	66%
	6MPH	Total (SLD)		63%	82	100%		63%	82	100%
		Shoulders			50	61%			31	38%
		Hips			33	40%			51	62%
90% BW	3MPH	Total (SLD)		82%	107	100%		80%	105	100%
		Shoulders			57	53%			33	31%
		Hips			51	48%			72	69%
	6MPH	Total (SLD)		78%	101	100%		75%	98	100%
		Shoulders			57	56%			36	37%
		Hips			44	44%			62	63%

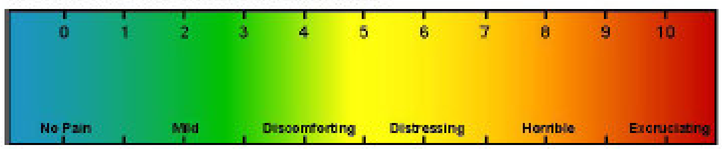
Subject 006 (S06) [205-lb]				GLENN				TVIS		
				Actual Avg. % of BW	[LBS]	[%]		Actual Avg. % of BW	[LBS]	[%]
60% BW	3MPH	Total (SLD)	Run 01-Static Loads Measured; 170-lb (83%); 125-lb (61%)	58%	118	100%	Run 05 Static Loads Measured; 164-lb (80%); 134-lb (65%)	63%	130	100%
		Shoulders			55	47%			80	62%
		Hips			63	53%			50	38%
	6MPH	Total (SLD)		56%	114	100%		61%	126	100%
		Shoulders			54	47%			85	67%
		Hips			60	53%			41	33%
90% BW	3MPH	Total (SLD)		77%	158	100%		75%	153	100%
		Shoulders			79	50%			87	57%
		Hips			79	50%			66	43%
	6MPH	Total (SLD)		74%	152	100%		71%	146	100%
		Shoulders			84	55%			94	64%
		Hips			68	45%			52	36%
60% BW	3MPH	Total (SLD)	Run 02 Static Loads Measured; 170-lb (83%); 135-lb (66%)	63%	129	100%	Run 06 Static Loads Measured; 162-lb (79%); 137-lb (67%)	66%	136	100%
		Shoulders			96	74%			90	66%
		Hips			33	26%			46	34%
	6MPH	Total (SLD)		61%	125	100%		64%	132	100%
		Shoulders			98	78%			92	70%
		Hips			27	22%			40	30%
90% BW	3MPH	Total (SLD)		77%	158	100%		74%	151	100%
		Shoulders			105	66%			91	60%
		Hips			56	35%			60	40%
	6MPH	Total (SLD)		74%	152	100%		71%	145	100%
		Shoulders			111	73%			101	70%
		Hips			41	27%			44	30%
60% BW	3MPH	Total (SLD)	Run 03 Static Loads Measured; 170-lb (83%); 135-lb (66%)	63%	130	100%	Run 07 Static Loads Measured; 164-lb (80%); 131-lb (64%)	61%	125	100%
		Shoulders			88	68%			89	71%
		Hips			42	32%			36	29%
	6MPH	Total (SLD)		61%	126	100%		60%	122	100%
		Shoulders			89	71%			92	75%
		Hips			37	29%			30	25%
90% BW	3MPH	Total (SLD)		77%	158	100%		75%	153	100%
		Shoulders			105	66%			100	65%
		Hips			53	34%			53	35%
	6MPH	Total (SLD)		74%	152	100%		71%	146	100%
		Shoulders			109	72%			105	72%
		Hips			43	28%			41	28%
60% BW	3MPH	Total (SLD)	Run 04 Static Loads Measured; 170-lb (83%); 143-lb (70%)	68%	140	100%	Run 08 Static Loads Measured			
		Shoulders			88	63%				
		Hips			52	37%				
	6MPH	Total (SLD)		65%	133	100%				
		Shoulders			86	65%				
		Hips			47	35%				
90% BW	3MPH	Total (SLD)		77%	158	100%				
		Shoulders			96	61%				
		Hips			62	39%				
	6MPH	Total (SLD)		74%	152	100%				
		Shoulders			100	66%				
		Hips			52	34%				

Appendix B: Comfort Questionnaire and Comfort vs. Load Data

CSM/TVIS Harness Comfort Questionnaire (Page 1)

1. Specify harness used: CSM harness or TVIS harness
2. Estimate the load applied to the harness or specify # of bungees and French clips
3. Approximate the ratio of loading on your hips and shoulders (respond % hip : % shoulder)
4. Did you wear the harness around your waist or around your hips? (respond waist or hips)
5. Did you use any auxiliary padding? (respond Yes/No and if yes specify what and where)
6. Approximate the speed of the treadmill during your fastest period of walking/running
7. Using the modified Borg scale below, please rate your discomfort at the following regions while walking/running (respond with a number for each region):
   a. Neck
   b. Shoulders
   c. Back
   d. Hips
   e. Waist
   f. Overall

Adapted from: McCaffery M. & Beebe A. Pain: Clinical Manual for Nursing Practice. St. Louis, MO: CV Mosby Co. 1989.
Used with permission. May be duplicated and used in clinical practice.



8. Any additional comments about the harness worn or load comfort

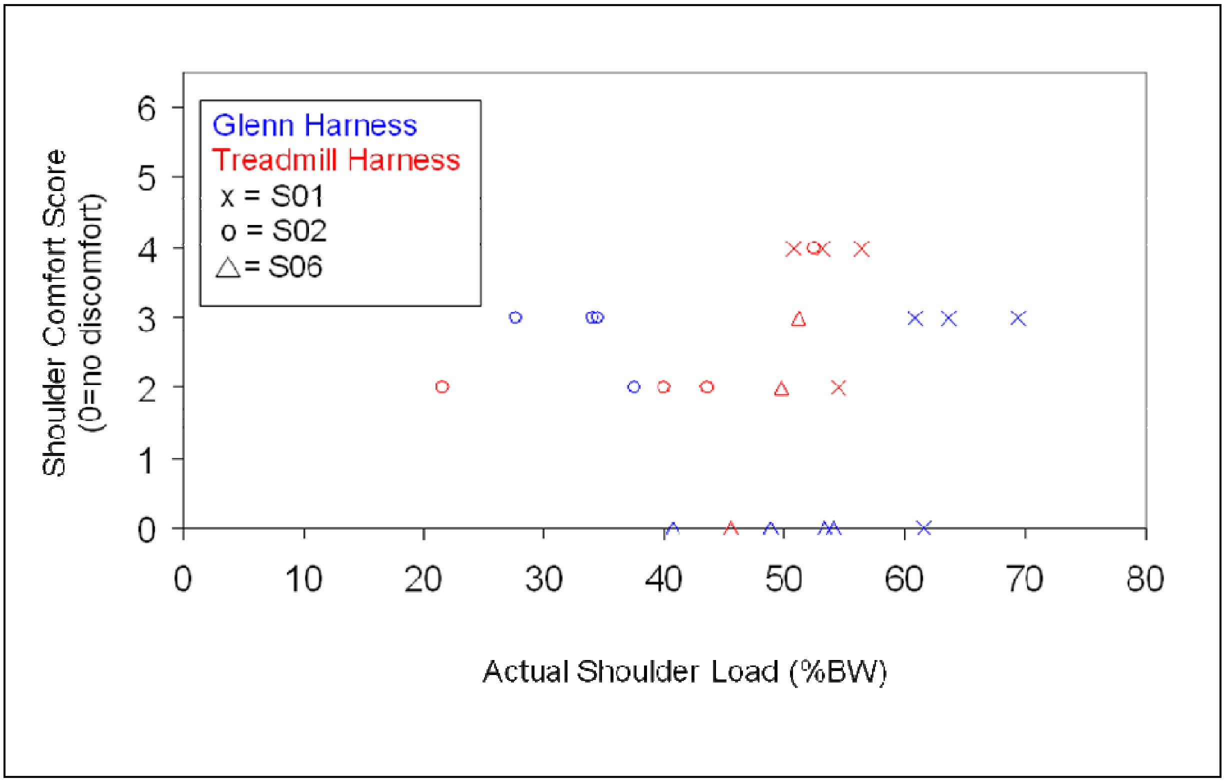
PLEASE TURN TO REVERSE TO CONTINUE

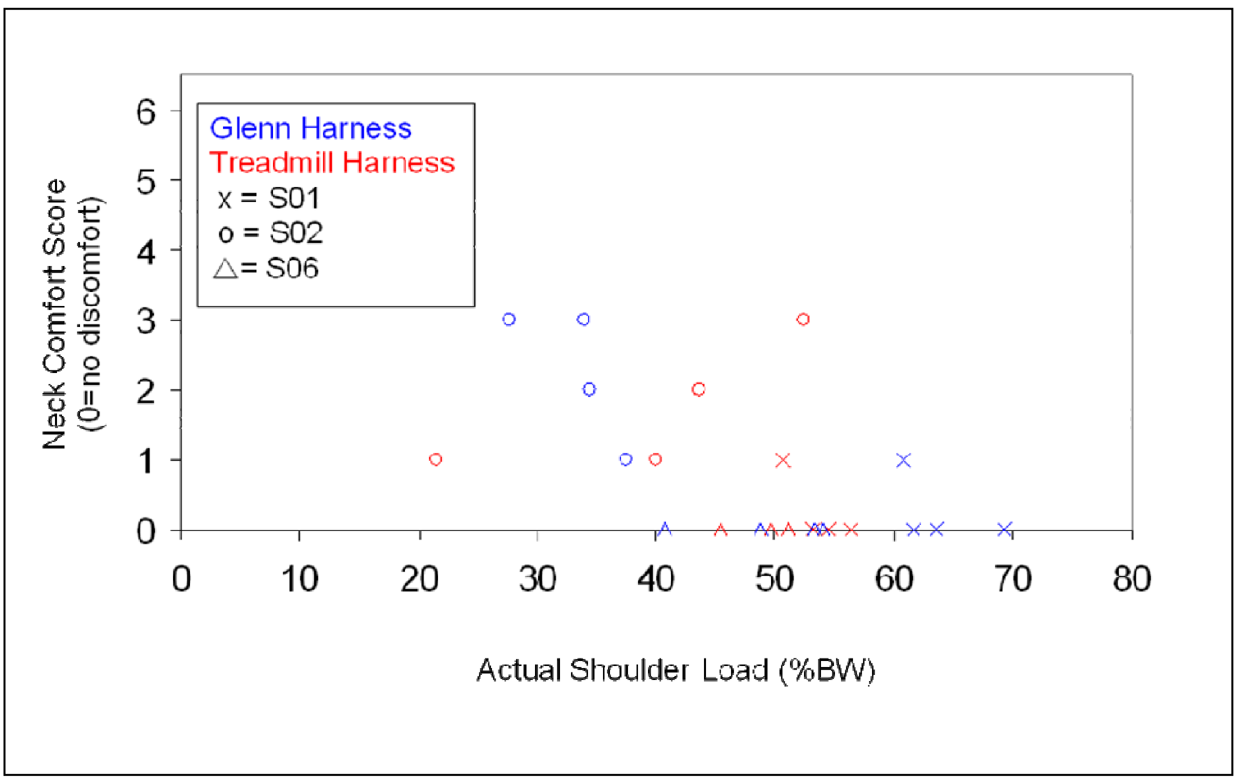
CSM/TVIS Harness Comfort Questionnaire (Page 2)

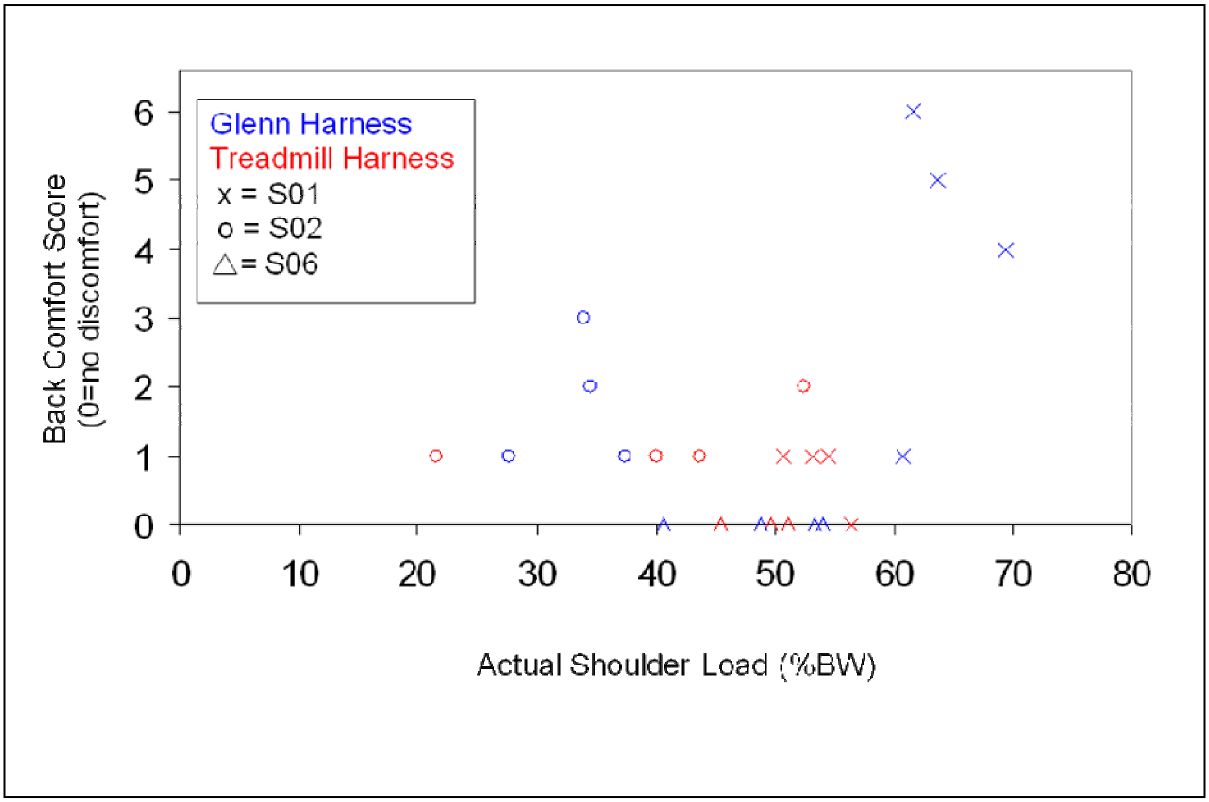
Rate the following with the provided scale (circle the number corresponding to your answer)

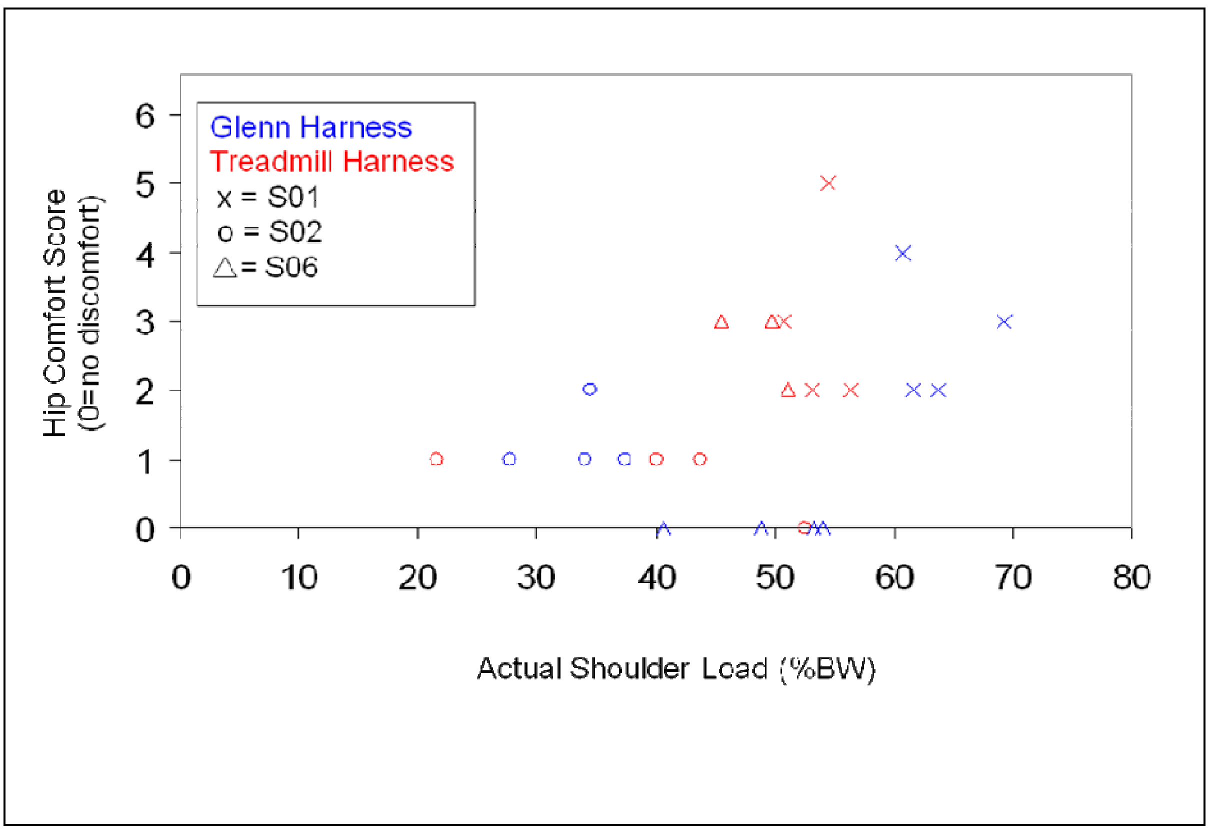
Strongly Disagree 1	Disagree 2	Neither agree nor disagree 3	Agree 4	Strongly Agree 5

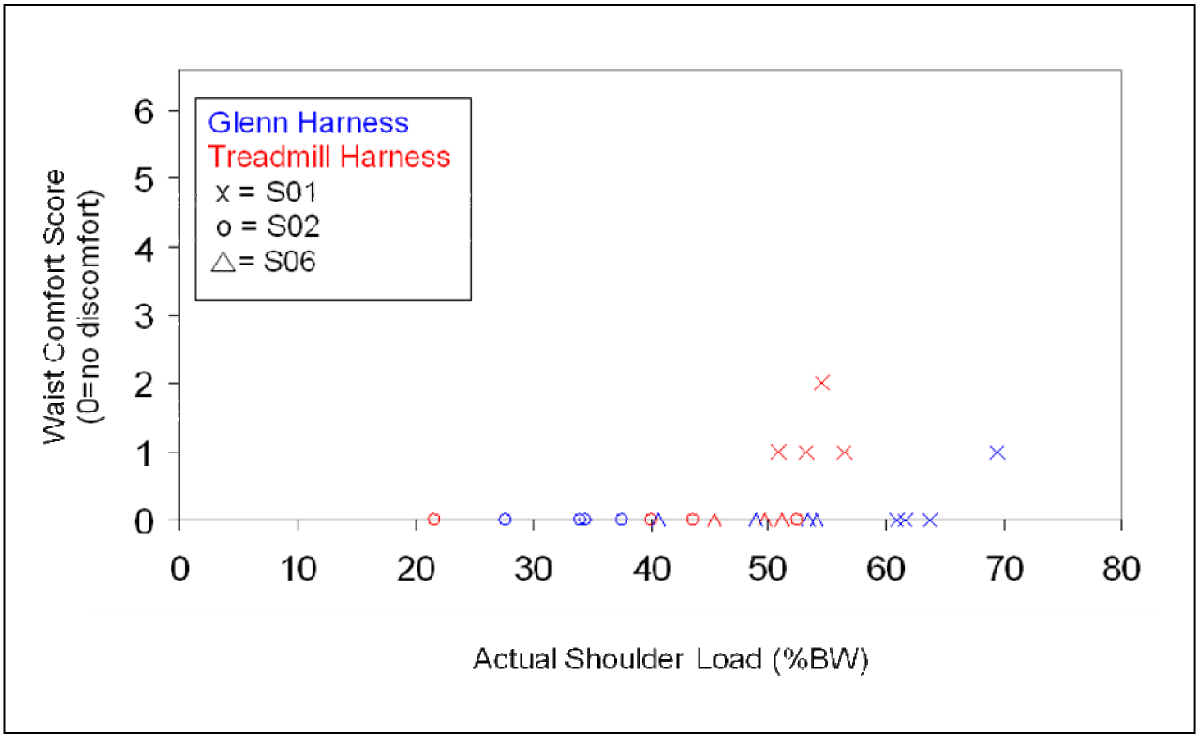
9. The hip belt folds or buckles when in use	1	2	3	4	5
10. The hip belt fits snugly about your waist	1	2	3	4	5
11. The harness is effective in distributing load between the waist/hips and the shoulders	1	2	3	4	5
12. The shoulder straps effectively spread load over the entire shoulder area	1	2	3	4	5
13. The harness constricts the chest and impedes breathing	1	2	3	4	5
14. The fit of the harness is adequate	1	2	3	4	5
15. Each crew member needs an individual harness	1	2	3	4	5
16. The harness provides sufficient adjustability	1	2	3	4	5
17. Harness requires adjustment while exercising	1	2	3	4	5

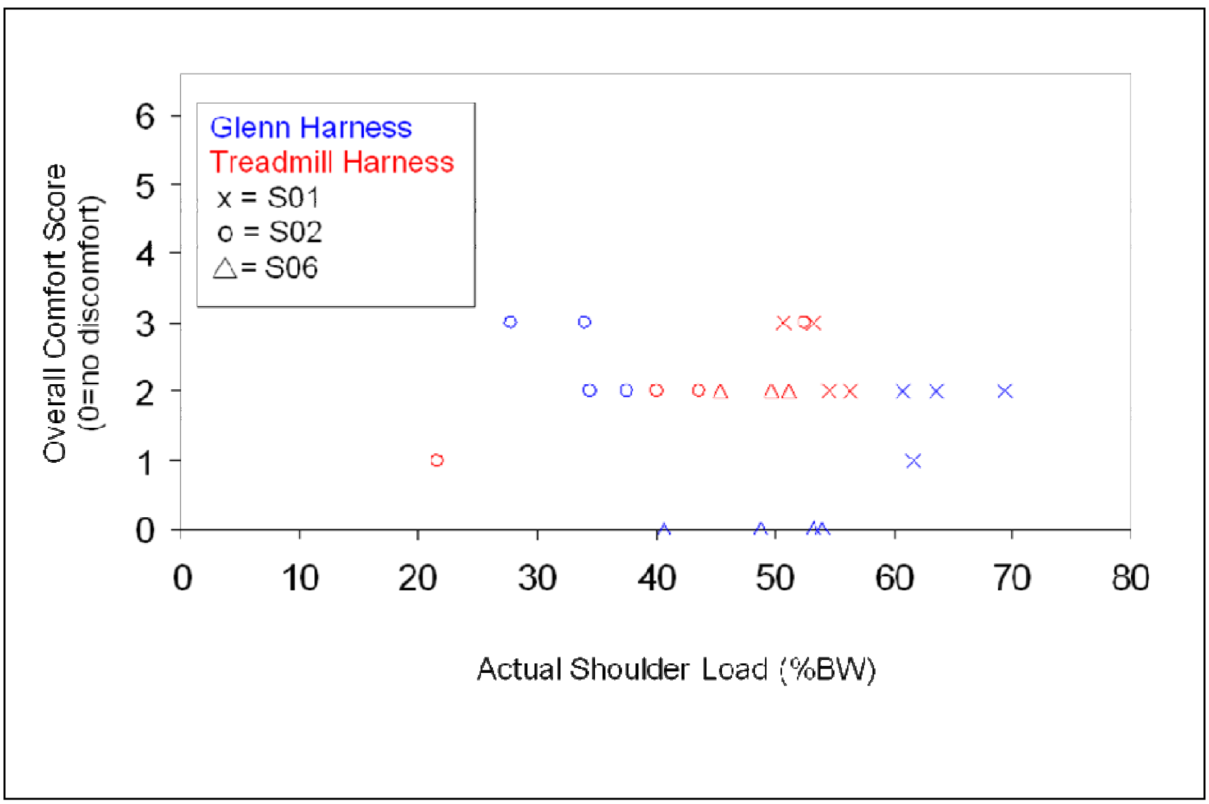

Glenn Harness
Treadmill Harness
x = S01
o = S02
△= S06
Shoulder Comfort Score
(0=no discomfort)
0
1
2
3
4
5
6
0
10
20
30
40
50
60
70
80
Actual Shoulder Load (%BW)


Glenn Harness
Treadmill Harness
x = S01
o = S02
△= S06
Neck Comfort Score
(0=no discomfort)
0
1
2
3
4
5
6
0
10
20
30
40
50
60
70
80
Actual Shoulder Load (%BW)

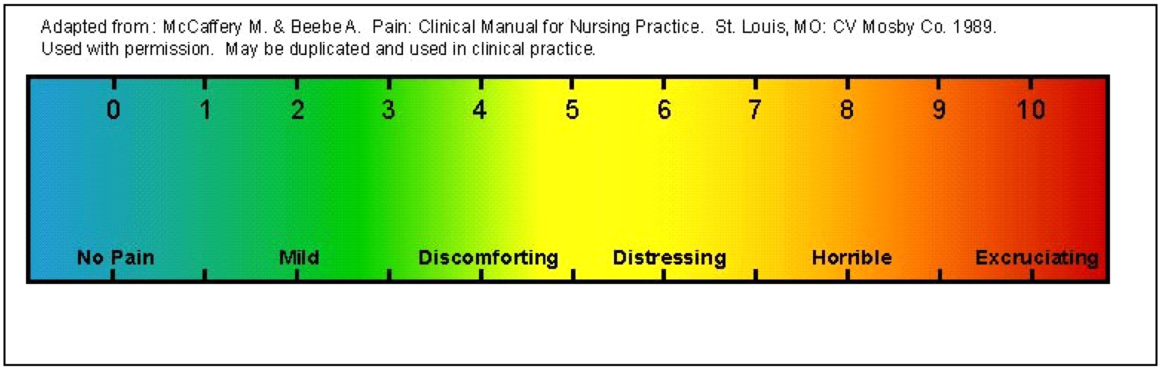

Glenn Harness
Treadmill Harness
x = S01
o = S02
△= S06
Back Comfort Score
(0=no discomfort)
Actual Shoulder Load (%BW)
0
1
2
3
4
5
6
0
10
20
30
40
50
60
70
80

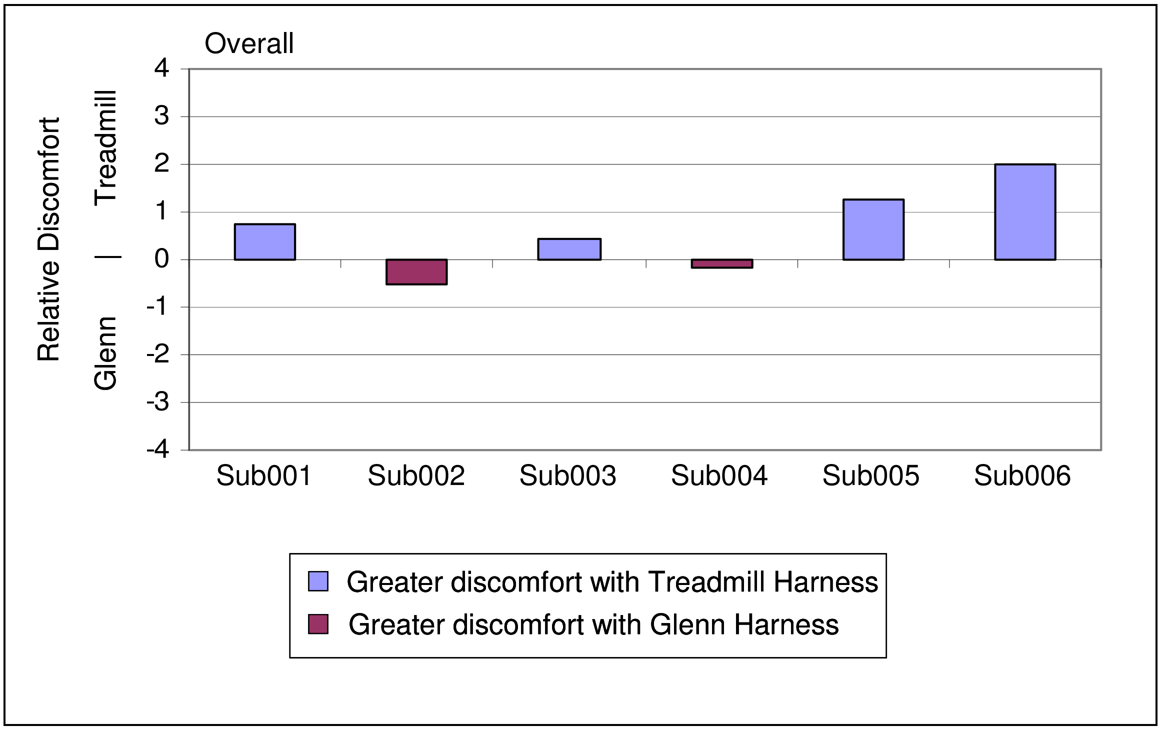

Glenn Harness
Treadmill Harness
x = S01
o = S02
△= S06
Hip Comfort Score
(0=no discomfort)
Actual Shoulder Load (%BW)
0
1
2
3
4
5
6
0
10
20
30
40
50
60
70
80


Glenn Harness
Treadmill Harness
x = S01
o = S02
△= S06
Waist Comfort Score
(0=no discomfort)
0
1
2
3
4
5
6
0
10
20
30
40
50
60
70
80
Actual Shoulder Load (%BW)


Glenn Harness
Treadmill Harness
x = S01
o = S02
△= S06
Overall Comfort Score
(0=no discomfort)
0
1
2
3
4
5
6
0
10
20
30
40
50
60
70
80
Actual Shoulder Load (%BW)

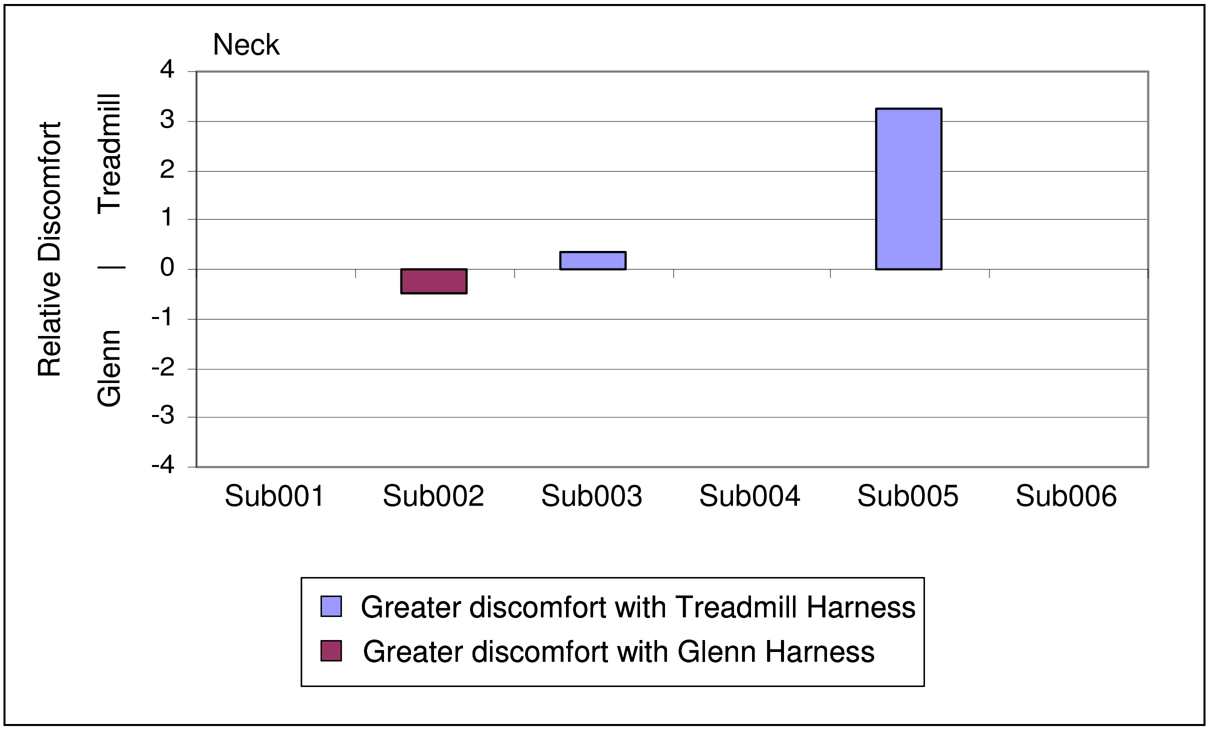
Appendix C: Borg Scale Data for Pain

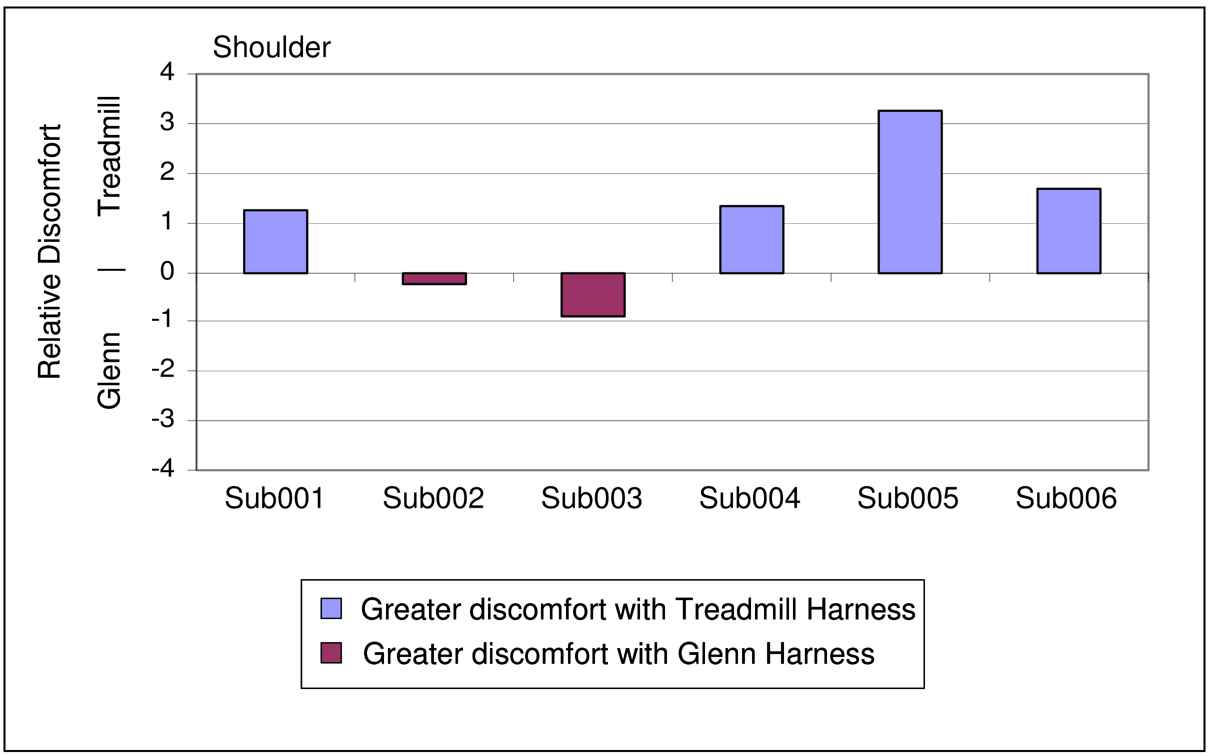


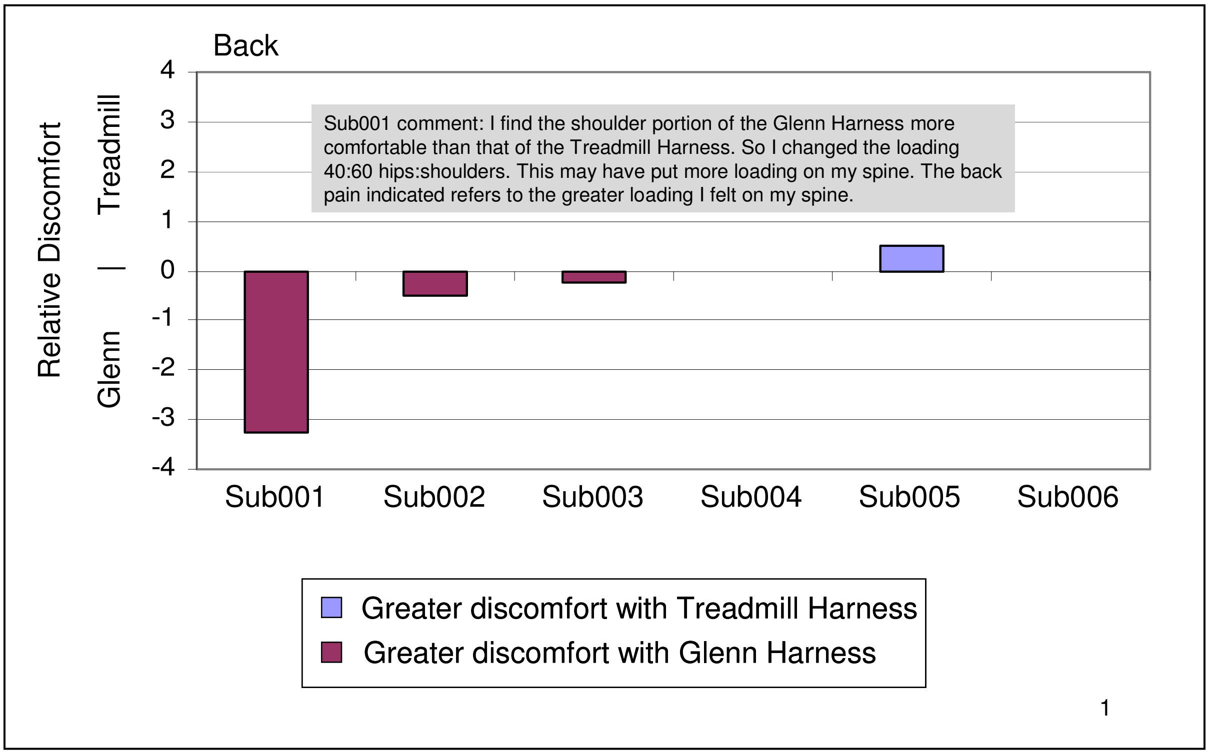


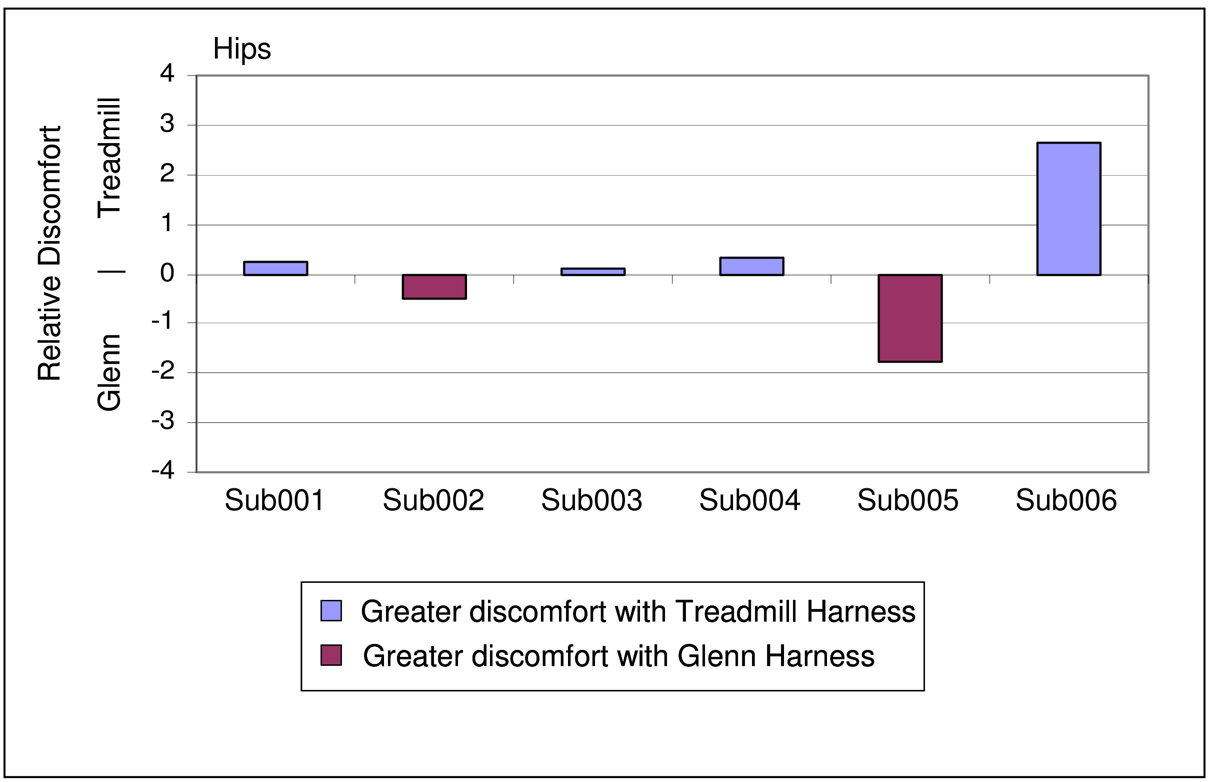
The "Overall" Relative Discomfort data plot above was generated by taking the numerical difference of the average pain rankings for each harness type, as reported by each crewmember. As opposed to plotting absolute pain values on one data plot, since pain is a relative notion (varies with the individual) [6], the relative differences in pain between harness type were plotted.

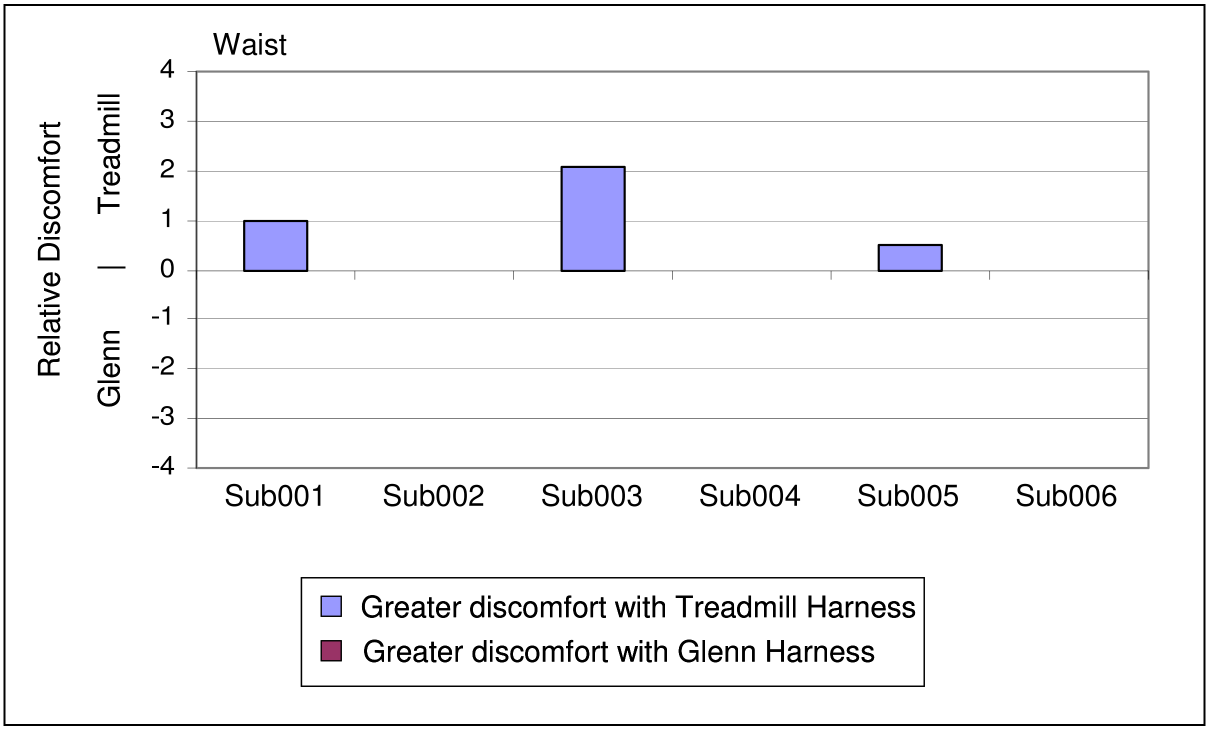
These data also nicely follow the crew narrative responses and crew debriefs in terms of which harness was preferred – Sub002 preferred Treadmill Harness, Sub004 stated no preference, and the four other crewmembers who indicated greater relative discomfort with Treadmill Harness, (Sub001, Sub003, Sub005, Sub006) preferred the Glenn Harness.


Neck
Relative Discomfort
Glenn | Treadmill
4
3
2
1
0
-1
-2
-3
-4
Sub001
Sub002
Sub003
Sub004
Sub005
Sub006
Greater discomfort with Treadmill Harness
Greater discomfort with Glenn Harness

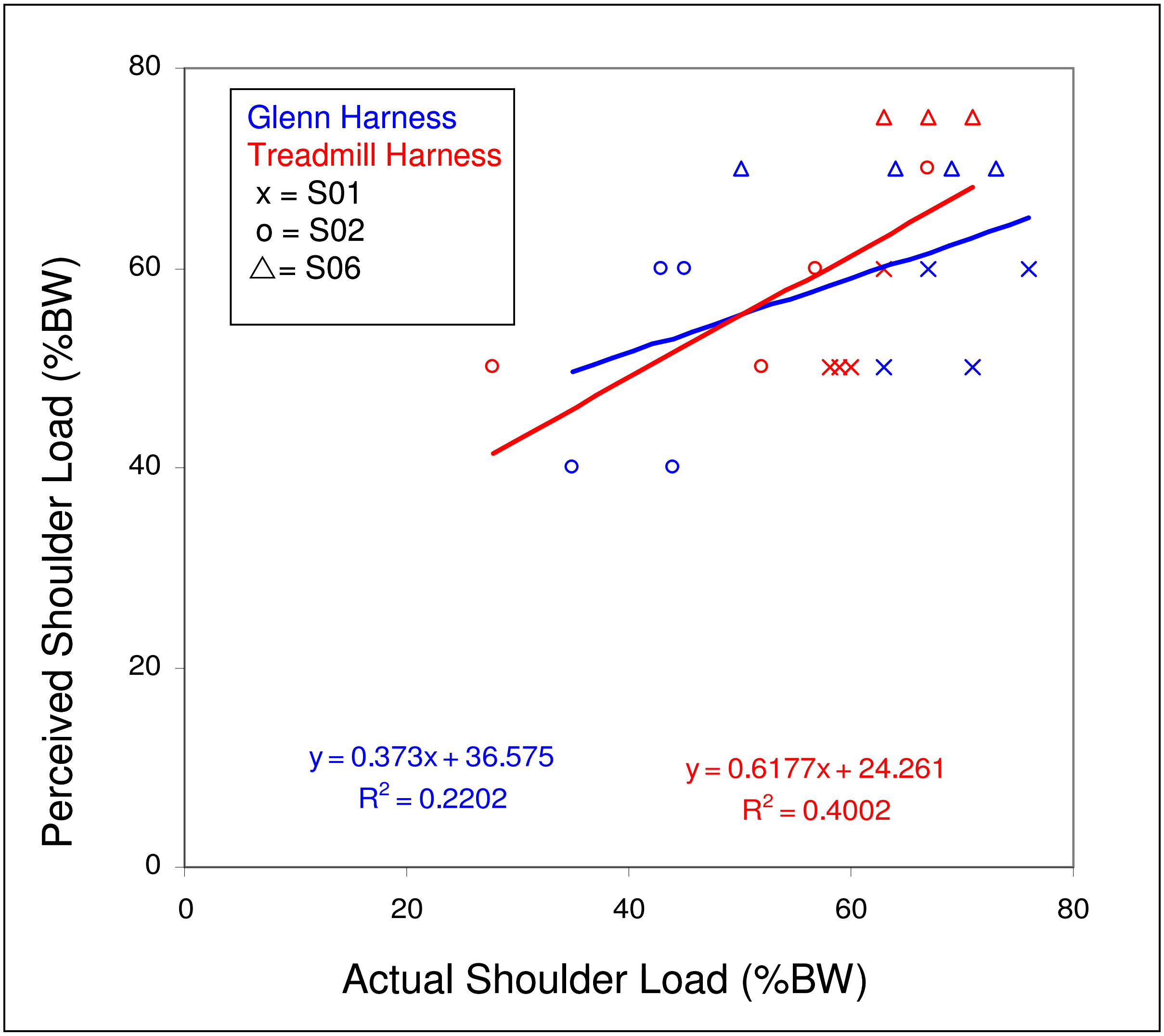

Shoulder
Relative Discomfort
Glenn | Treadmill
4
3
2
1
0
-1
-2
-3
-4
Sub001
Sub002
Sub003
Sub004
Sub005
Sub006
Greater discomfort with Treadmill Harness
Greater discomfort with Glenn Harness


Back
Relative Discomfort
Glenn | Treadmill
4
3
2
1
0
-1
-2
-3
-4
Sub001 comment: I find the shoulder portion of the Glenn Harness more comfortable than that of the Treadmill Harness. So I changed the loading 40:60 hips:shoulders. This may have put more loading on my spine. The back pain indicated refers to the greater loading I felt on my spine.
Sub001
Sub002
Sub003
Sub004
Sub005
Sub006
Greater discomfort with Treadmill Harness
Greater discomfort with Glenn Harness
1

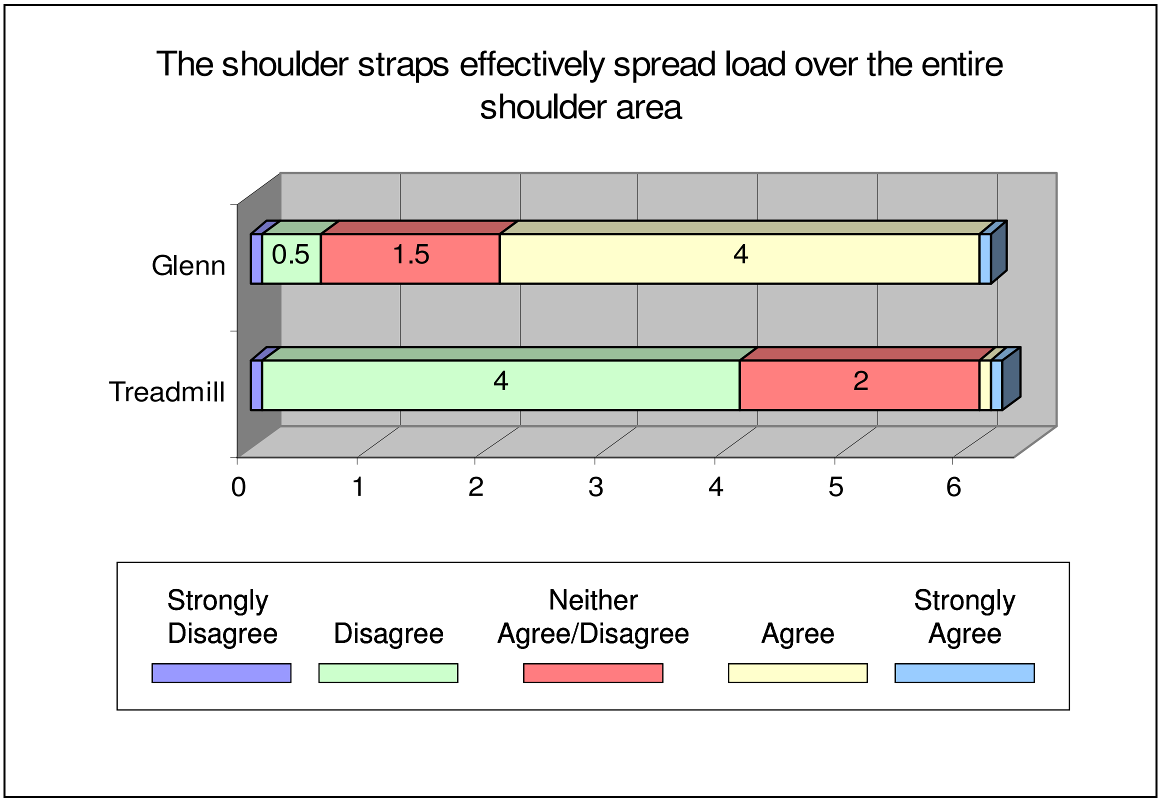

Hips
Relative Discomfort
Glenn | Treadmill
4
3
2
1
0
-1
-2
-3
-4
Sub001
Sub002
Sub003
Sub004
Sub005
Sub006
Greater discomfort with Treadmill Harness
Greater discomfort with Glenn Harness

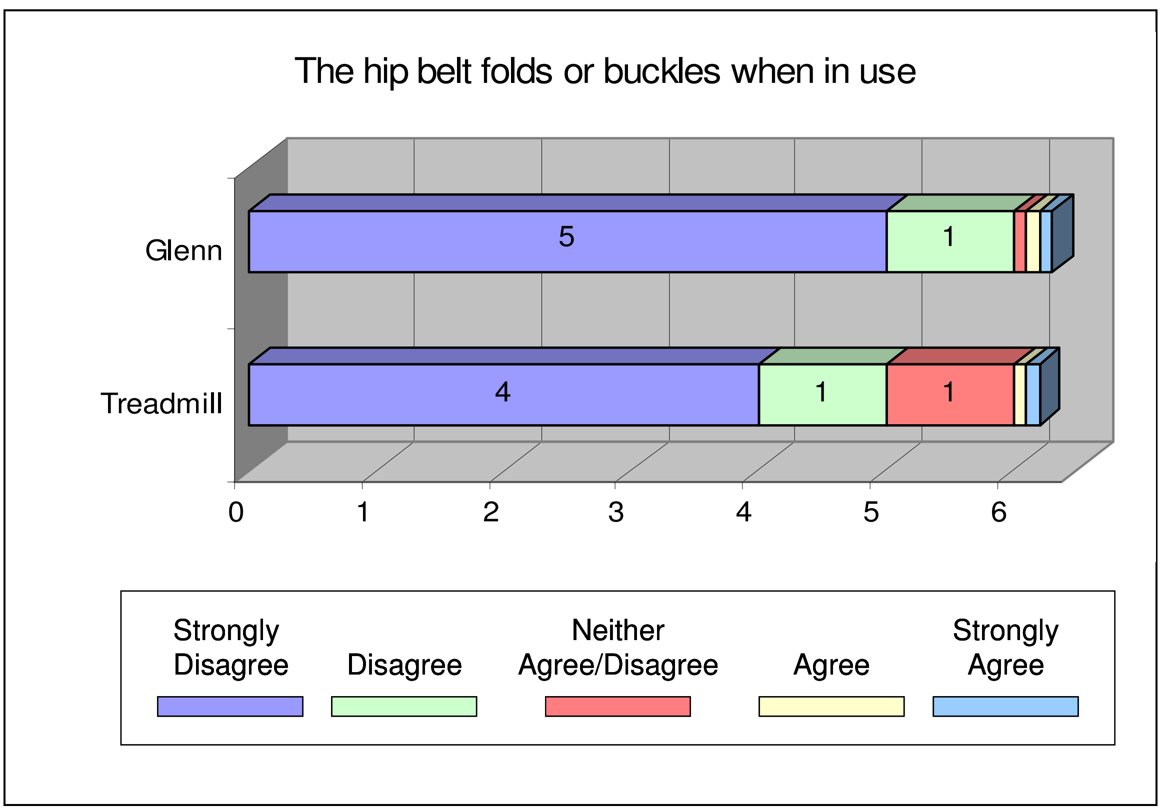

Waist
Relative Discomfort
Glenn | Treadmill
4
3
2
1
0
-1
-2
-3
-4
Sub001
Sub002
Sub003
Sub004
Sub005
Sub006
Greater discomfort with Treadmill Harness
Greater discomfort with Glenn Harness

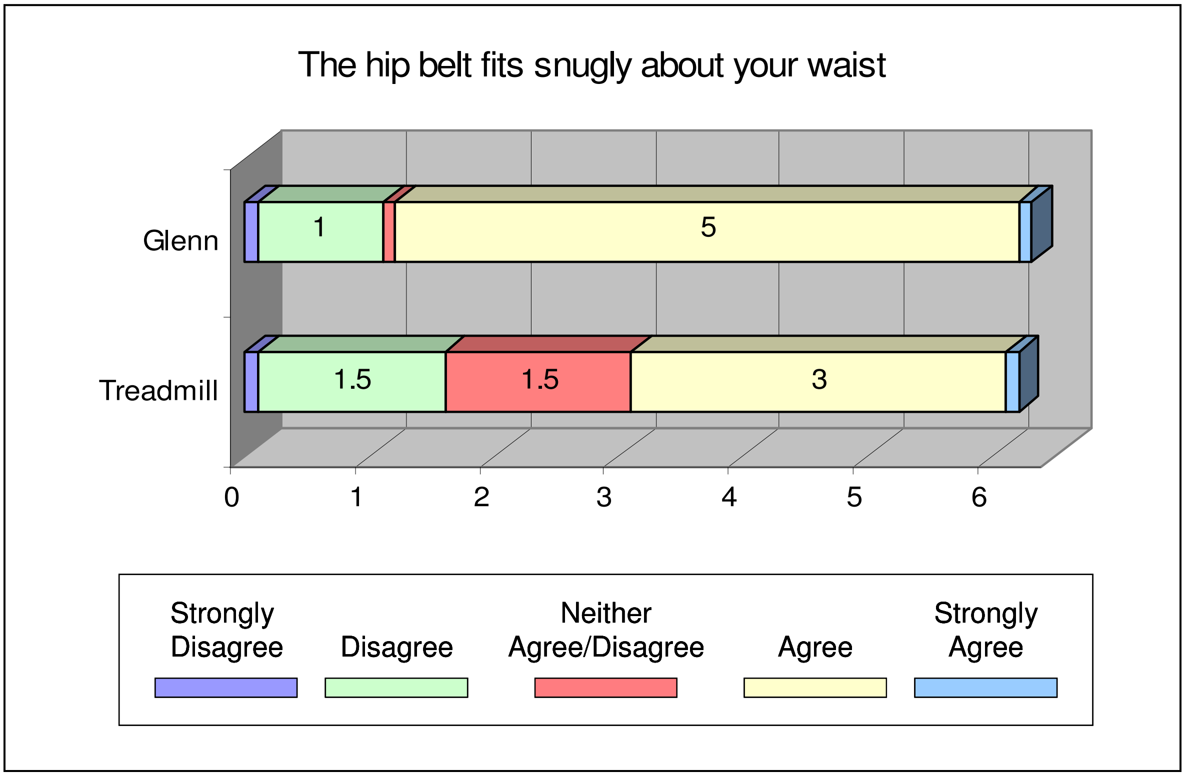
Appendix D: Actual Load vs. Perceived Load by Harness Type

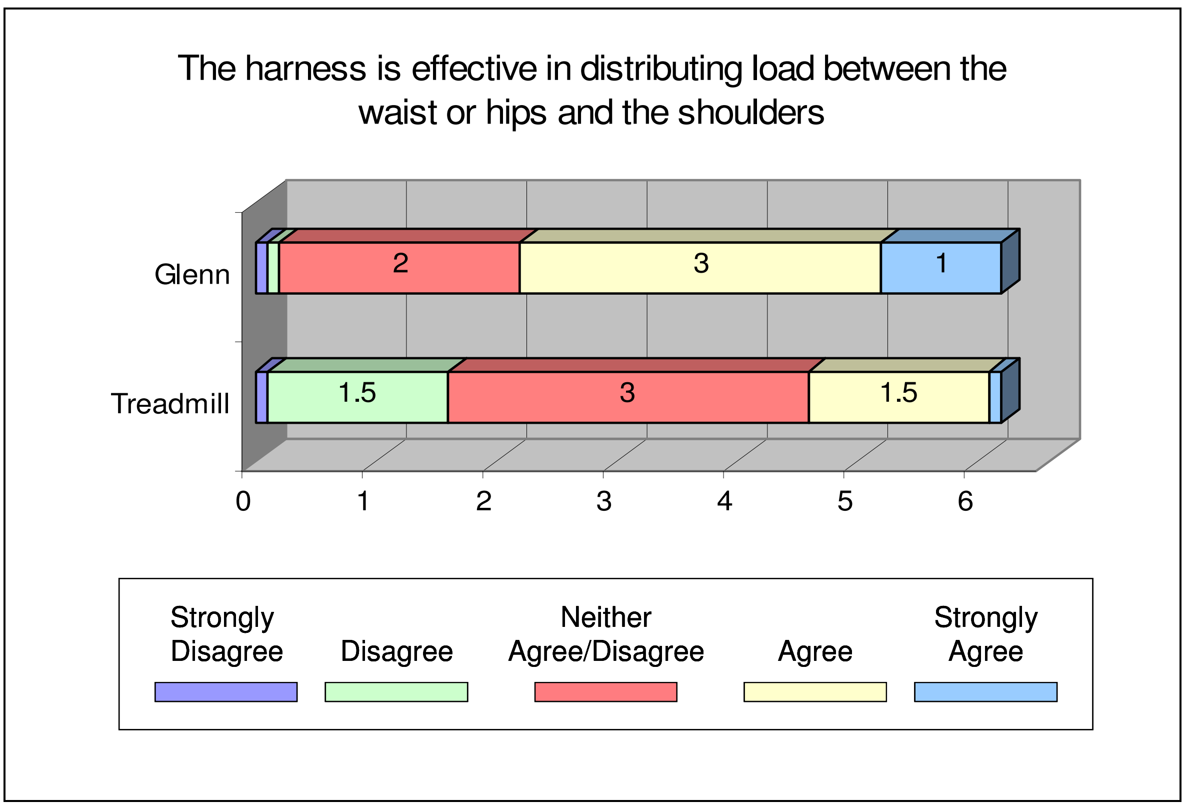


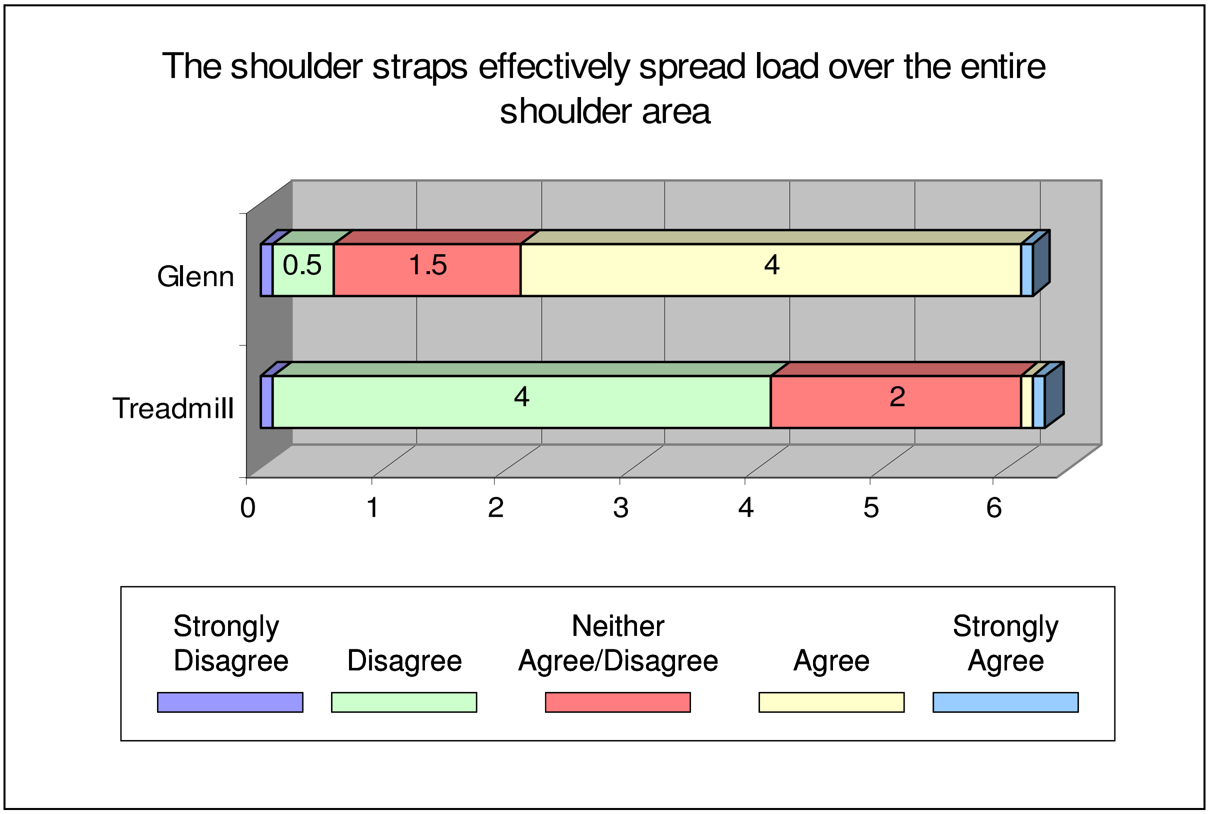
Appendix E: Likert Scale Responses

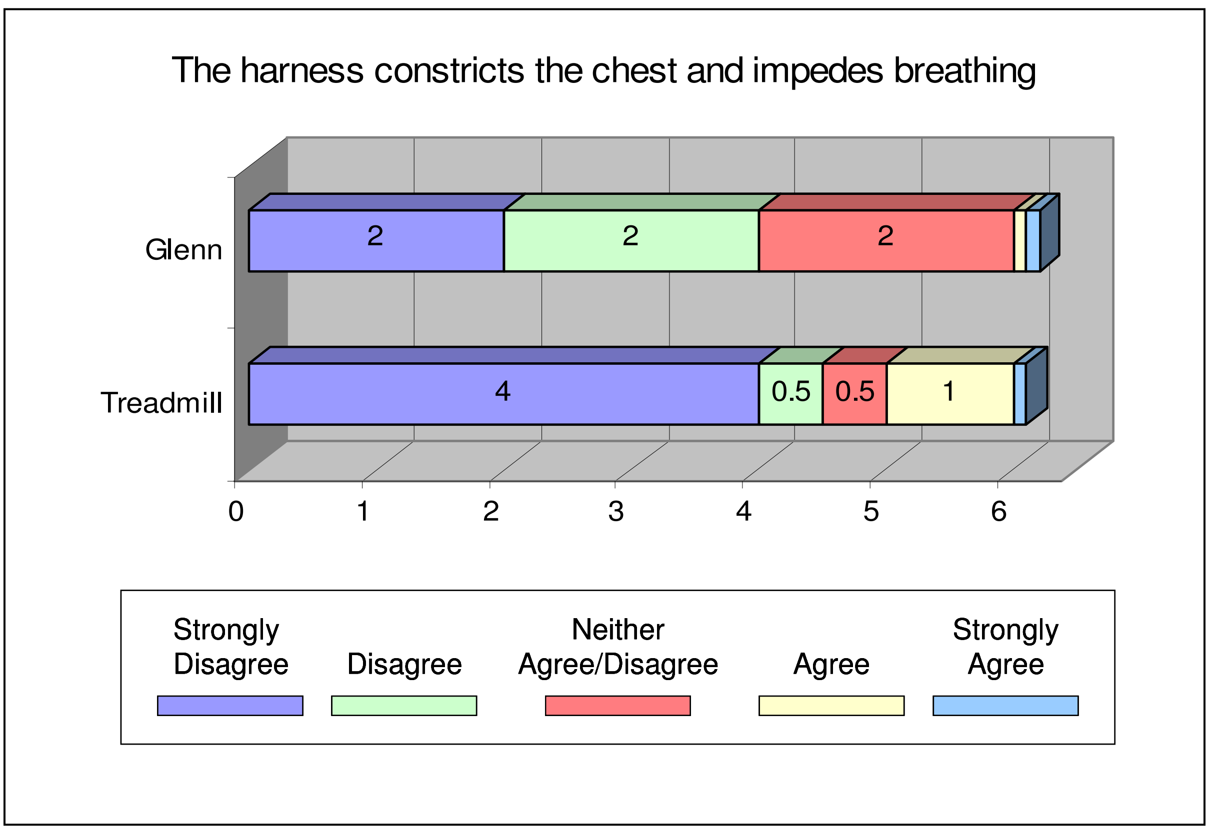


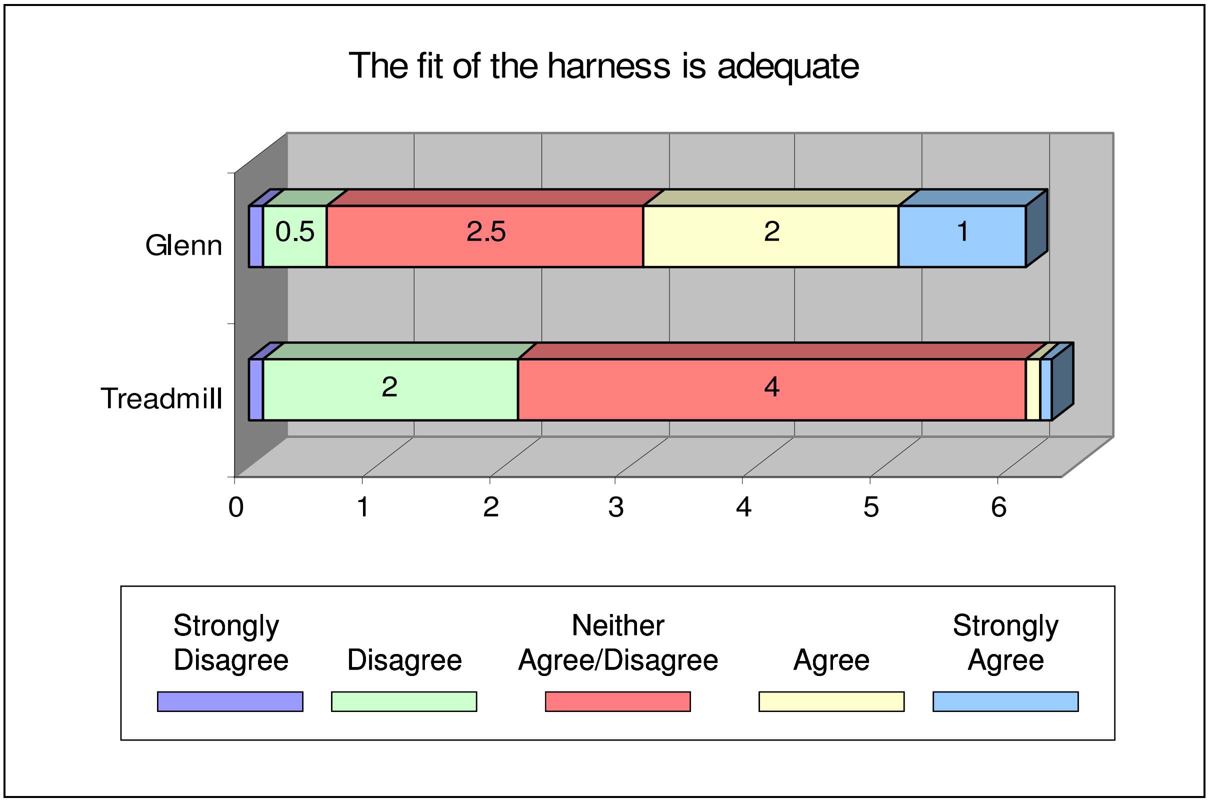


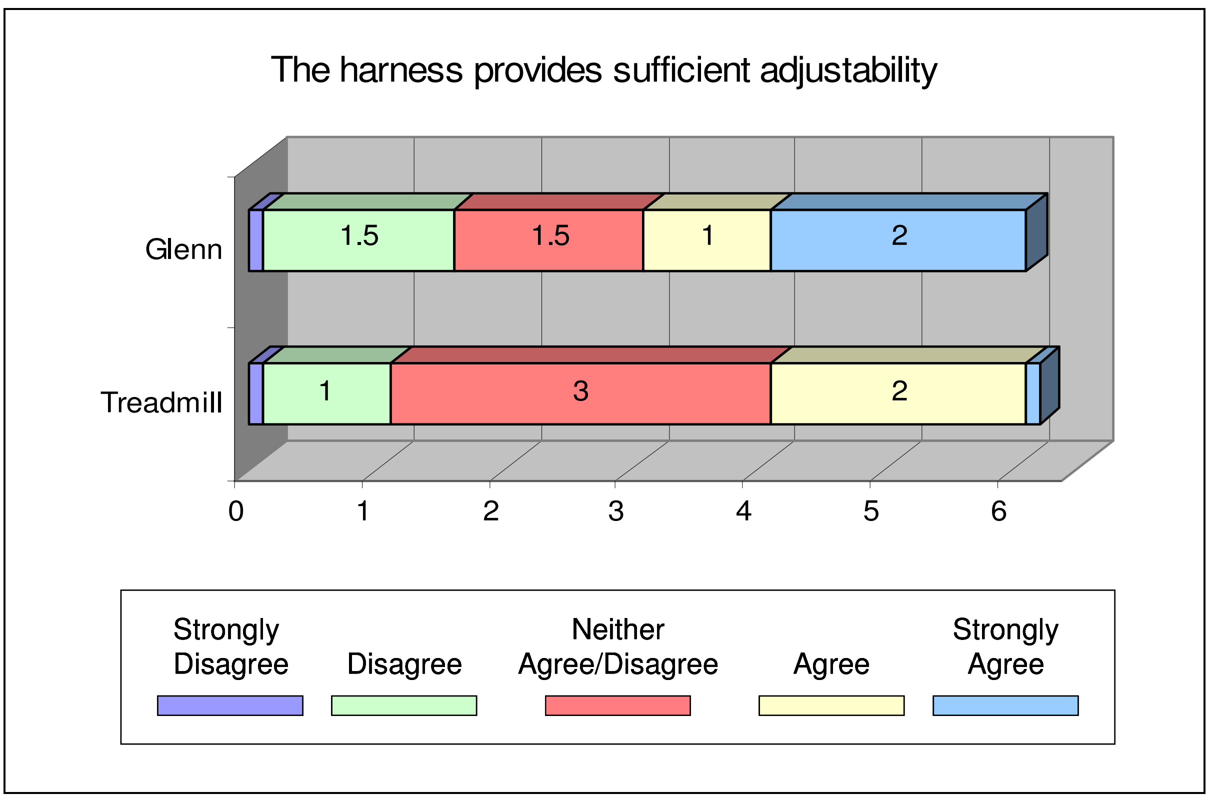

The hip belt fits snugly about your waist
Glenn
Treadmill
1
5
1.5
1.5
3
0
1
2
3
4
5
6
Strongly Disagree
Disagree
Neither Agree/Disagree
Agree
Strongly Agree


The harness is effective in distributing load between the waist or hips and the shoulders
Glenn
Treadmill
2
3
1
1.5
3
1.5
0
1
2
3
4
5
6
Strongly Disagree
Disagree
Neither Agree/Disagree
Agree
Strongly Agree


The shoulder straps effectively spread load over the entire shoulder area
Glenn
Treadmill
0.5
1.5
4
4
2
0
1
2
3
4
5
6
Strongly Disagree
Disagree
Neither Agree/Disagree
Agree
Strongly Agree


The harness constricts the chest and impedes breathing
Glenn
Treadmill
2
2
2
4
0.5
0.5
1
0
1
2
3
4
5
6
Strongly Disagree
Disagree
Neither Agree/Disagree
Agree
Strongly Agree


The fit of the harness is adequate
Glenn
Treadmill
0.5
2.5
2
1
2
4
0
1
2
3
4
5
6
Strongly Disagree
Disagree
Neither Agree/Disagree
Agree
Strongly Agree


The harness provides sufficient adjustability
Glenn
Treadmill
1.5
1.5
1
2
1
3
2
0
1
2
3
4
5
6
Strongly Disagree
Disagree
Neither Agree/Disagree
Agree
Strongly Agree

Appendix F: Quick Summary of Statistical Analysis

Item 1: analyze the comfort score between the harnesses include all possible design variables and gender.

The measurements are repeat measures taken in time order within a single subject. Because of the nature of the repeated measures and the fact that only males wore the harness around the waist gender and where worn are confounded. Since we are interested in examining the effect of gender the terms that were included in the multivariate analysis were gender, harness, BW, and MPH.

~~~~~~

Multivariate analysis of comfort score for **Shoulders**
Full model terms are: gender harness BW MPH

Obs	Effect	Num DF	Den DF	FValue	P-Value
1	gender	1	4	0.18	0.6953
2	**Harness**	**1**	**5**	**49.52**	**0.0009**
3	BW	1	159	0.01	0.9215
4	MPH	1	159	0.01	0.9431

~~~~~~

Shoulder Rating Averages by Harness Type

Obs	Harness	LS Mean	StdErr
1	Glenn	2.52	0.99
2	Tread	3.42	0.99

Multivariate analysis of comfort score for **Back**
Full model terms are: gender harness BW MPH

Obs	Effect	Num DF	Den DF	FValue	P-Value
1	gender	1	4	0.16	0.7137
2	**Harness**	**1**	**5**	**34.01**	**0.0021**
3	BW	1	159	0.06	0.8080
4	MPH	1	159	0.03	0.8602

~~~~~~

Back Rating Averages by Harness Type

Obs	Harness	LS Mean	StdErr
1	Glenn	1.97	0.96
2	Tread	1.23	0.96
~~~~~~

Multivariate analysis of comfort score for **Hips**
Full model terms are: gender harness BW MPH

Obs	Effect	Num DF	Den DF	FValue	P-Value
1	gender	1	4	0.99	0.3754
2	Harness	1	5	0.48	0.5207
3	BW	1	159	0.59	0.4446
4	MPH	1	159	0.31	0.5793

~~~~~~

Multivariate analysis of comfort score for **Waist**
Full model terms are: gender harness BW MPH

Obs	Effect	Num DF	Den DF	FValue	P-Value
1	gender	1	4	0.66	0.4621
2	**Harness**	**1**	**5**	**45.50**	**0.0011**
3	BW	1	159	0.25	0.6206
4	MPH	1	159	0.13	0.7196

~~~~~~

Waist Rating Averages by Harness Type

Obs	Harness	LS Mean	StdErr
1	Glenn	0.60	1.07
2	Tread	1.13	1.07

Multivariate analysis of comfort score for **Overall**
Full model terms are: gender harness BW MPH

Obs	Effect	Num DF	Den DF	FValue	P-Value
1	gender	1	4	0.33	0.5968
2	**Harness**	**1**	**5**	**41.45**	**0.0013**
3	BW	1	159	0.02	0.8833
4	MPH	1	159	0.01	0.9152

~~~~~~

Overall Rating Averages by Harness Type

Obs	Harness	LS Mean	StdErr
1	Glenn	2.43	1.12
2	Tread	2.98	1.12
~~~~~~

Item 2 analysis of the actual loads -restricted to 3 subjects

Multivariate analysis for **Actual Total Load**
Full model terms are: gender harness BW MPH

Obs	Effect	Num DF	Den DF	FValue	P-Value
1	gender	1	1	0.52	0.6029
2	Harness	1	2	0.24	0.6742
3	**BW**	**1**	**86**	**244.27**	**<.0001**
4	**MPH**	**1**	**86**	**11.75**	**0.0009**

~~~~~~

Multivariate analysis for Percent **Actual Shoulder Load**
Full model terms are: gender harness BW MPH

Obs	Effect	Num DF	Den DF	FValue	P-Value
1	gender	1	1	16.26	0.1548
2	Harness	1	2	1.80	0.3120
3	**BW**	**1**	**86**	**18.88**	**<.0001**
4	**MPH**	**1**	**86**	**38.94**	**<.0001**

~~~~~~

Multivariate analysis for Percent **Actual Hip Load**
Full model terms are: gender harness BW MPH

Obs	Effect	Num DF	Den DF	FValue	P-Value
1	gender	1	1	16.86	0.1521
2	Harness	1	2	1.51	0.3440
3	**BW**	**1**	**86**	**18.17**	**<.0001**
4	**MPH**	**1**	**86**	**38.77**	**<.0001**

Summary Item 1 and 2:

There were significant differences in average rating scores for Shoulders, Back, Waist and Overall due to harness type. There were no significant differences in actual or percent loads due to harness type.

Item 3 analysis of the correlation between actual loads and comfort scores - this will be restricted to 3 subjects.

Univariate analysis of Back ratings vs. Percent Actual Shoulder Load

Obs	Effect	Coefficient	StdErr	DF	P-Value
1	Intercept	−0.1933	0.8612	2	0.8433
2	Percent Shoulder	0.02661	0.01149	88	**0.0229**

~~~~~~

Univariate analysis of Back ratings vs. Percent Actual Hip Load

Obs	Effect	Coefficient	StdErr	DF	P-Value
1	Intercept	2.4911	0.7325	2	0.0767
2	Percent Hip	−0.02711	0.01147	88	**0.0203**

~~~~~~

Summary Item 3:

The only significant ($P < .05$) correlation between loads and comfort scores occurred with the Back ratings and the percent of shoulder and hip loadings.

Item 4 – Assessment of Perceived Shoulder and Hip Load and Responses to Questions 1-9 as a function of Harness Type

~~~~~~

Perceived Percent Shoulder Load by harness type

Obs	Harness	Mean_ Value	StdErr	P-Value for Mean Difference
1	Glenn	56.94	2.52	.67
2	Tread	57.38	2.54	

~~~~~~

Perceived Percent Hip Load by harness type

Obs	Harness	Mean_ Value	StdErr	P-Value for Mean Difference
1	Glenn	43.05	2.52	.67
2	Tread	42.61	2.54	

~~~~~~

Q1 by harness type

Obs	Harness	Mean_ Value	StdErr	P-Value for Mean Difference
1	Glenn	1.11	0.2610	**.0002**
2	Tread	1.53	0.2612	

~~~~~~

Q2 by harness type

Obs	Harness	Mean_ Value	StdErr	P-Value for Mean Difference
1	Glenn	3.64	0.246	**.0014**
2	Tread	3.20	0.247	

~~~~~~
~~~~~~

Q3 by harness type

Obs	Harness	Mean_ Value	StdErr	P-Value for Mean Difference
1	Glenn	3.81	0.190	**.0003**
2	Tread	3.07	0.192	

~~~~~~

Q4 by harness type

Obs	Harness	Mean_ Value	StdErr	P-Value for Mean Difference
1	Glenn	3.56	0.128	**<.0001**
2	Tread	2.15	0.131	

~~~~~~

Q5 by harness type

Obs	Harness	Mean_ Value	StdErr	P-Value for Mean Difference
1	Glenn	1.96	0.227	**.03**
2	Tread	1.58	0.230	

~~~~~~

Q6 by harness type

Obs	Harness	Mean_ Value	StdErr	P-Value for Mean Difference
1	Glenn	3.72	0.231	**.0001**
2	Tread	2.65	0.233	

~~~~~~

Q7 by harness type

Obs	Harness	Mean_ Value	StdErr	P-Value for Mean Difference
1	Glenn	4.72	0.248	**.0132**
2	Tread	4.44	0.249	

~~~~~~
~~~~~~

Q8 by harness type

Obs	Harness	Mean_ Value	StdErr	P-Value for Mean Difference
1	Glenn	3.58	0.252	**.0051**
2	Tread	3.17	0.253	

~~~~~~

Q9 by harness type

Obs	Harness	Mean_ Value	StdErr	P-Value for Mean Difference
1	Glenn	2.41	0.364	.18
2	Tread	2.59	0.365	

Summary Item 4:

Between harness types there were significant differences in mean Likert scores for Questions 1-8.
~~~~~~

Appendix G: On-Orbit Stills from Video Imagery

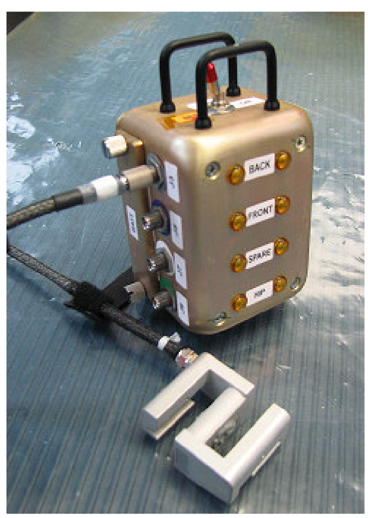
Glenn Harness – no instrumentation

Glenn Harness – with instrumentation

Glenn Harness – no instrumentation

Treadmill Harness – no instrumentation

Appendix H: Glenn Harness Flight Configuration



Junction Box (rear) and Buckle Transducer (front), typical

References

[1] Novotny S.C., Perusek G.P., Englehaupt R.K., Rice A.J., Comstock B., Bansal A., Cavanagh P.R., **A Harness for Treadmill Exercise in Space,** manuscript submitted to Aviation Space and Environmental Medicine, March 2011.

[2] Perusek G.P., DeWitt J.K., Just M.L., Cavanagh, P.R., et. al., Final Report to Exercise Countermeasures Project: **Treadmill with Vibration Isolation and Stabilization (TVIS) Harness Comfort Evaluation**, archived in Life Sciences Data Archives. August, 2007.

[3] Ferrer M.A., Young K., Velasquez L., Perusek G., Anthropometry and Biomechanics Facility (ABF) Memo ABF07-717, Concept Harness Human Factors Preliminary Evaluation for ISS TVIS, NASA Johnson Space Center, October 30, 2006.

[4] Curtis R. ed. The backpacker's field manual. New York: Three Rivers Press, 2005.

[5] Fletcher C, Rawlins C L. Complete walker 4. Alfred A. Knopf, 2002.

[6] Gunnar Borg, Borg’s Perceived Exertion and Pain Scales, Human Kinetics Press, 1998.